

U.S. Mines Bureau

Bulletin 48

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

JOSEPH A. HOLMES, DIRECTOR

THE SELECTION OF EXPLOSIVES

USED IN

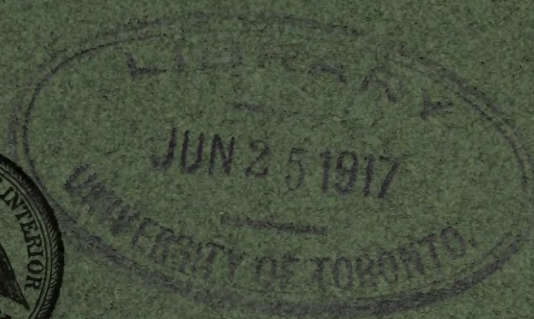
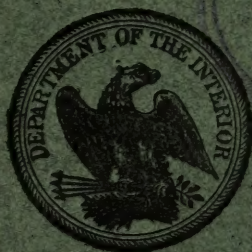
ENGINEERING AND MINING OPERATIONS

BY

CLARENCE HALL

AND

SPENCER P. HOWELL



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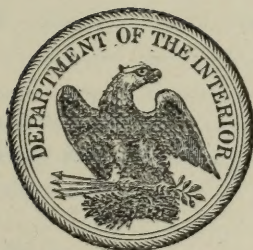
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THE SELECTION OF EXPLOSIVES USED IN ENGINEERING AND MINING OPERATIONS.

By CLARENCE HALL and SPENCER P. HOWELL.

GENERAL STATEMENT.

This bulletin deals with the characteristic features of the principal explosives used in mining and engineering operations, and especially with the tests that show the suitability of different classes of explosives for different kinds of work. The Bureau of Mines publishes the report as one of a series dealing with tests of explosives and methods of reducing the risks involved in the use of explosives in mining operations.

The application of explosives to engineering and mining operations has increased rapidly in recent years. According to a preliminary report issued by the Bureau of the Census, 469,000,000 pounds of explosives was manufactured in this country during the year 1909, and the greater part of this production was used for industrial purposes.

In large engineering projects and in mining operations requiring the use of explosives the selection of a suitable explosive from the many varieties offered for sale is of fundamental importance. Various considerations are involved in the selection of an explosive of proper class for the blasting to be done. Many explosives suitable for quarry work are unsuitable for use in deep mines or in close workings. In metal mining and in driving tunnels the character of the gases evolved by the explosive on detonation is an important consideration. An explosive for use in gaseous or dusty coal mines must be formulated and compounded so that its flame temperature and the height and duration of its flame are reduced enough to permit its being used with comparative safety. In wet workings or in submarine blasting explosives impervious to moisture are requisite. In extremely cold climates explosives that do not require thawing are desirable, provided they are equally good in other respects. An essential requirement of all explosives, especially of those for use in tropical countries, is that they shall remain stable without change in chemical or physical characteristics.

Because of the varying conditions in the different projects on which explosives are used, it is necessary to emphasize the fact that some characteristics of explosives are of much importance in certain classes of work and of little or no importance in others.

EXPLOSIVES USED IN QUARRY OPERATIONS.

Practically every class and every grade of commercial explosive are used in open-air work to meet varying conditions. In breaking down rock in quarries the explosives generally employed are: Black blasting powder, granulated nitroglycerin powder containing 5 to 15 per cent of nitroglycerin, "straight" nitroglycerin dynamites containing 15 to 60 per cent of nitroglycerin, low-freezing dynamites commercially rated according to the equivalent percentage of strength of the "straight" nitroglycerin dynamites, and ammonia dynamites rated in a similar way. In recent years blasting gelatin, gelatin dynamites, ammonium-nitrate powders containing nitro-substitution compounds, chlorate powders, and the so-called nitro-starch powders have been used to a small extent in quarry work.

BLACK BLASTING POWDER.

Black blasting powder is a mechanical mixture; it consists of finely pulverized sodium nitrate intimately associated with combustible materials. This intimate association of the materials is brought about by thoroughly mixing and incorporating them in what are technically termed wheel mills. The product is pressed into hard cakes, which are subsequently broken into small grains. The powder is then put in a revolving barrel where the grains are rounded by rubbing together, and at the same time are coated with graphite or, as the operation is often termed, "glazed." The object of rounding and glazing the grains is to render them free-running; the glazing also serves to delay somewhat their taking up moisture from the air.

The following is the composition of the black blasting powder that is generally offered for sale in this country:

Composition of commercial black blasting powder.

Charcoal.....	16
Sulphur.....	11
Sodium nitrate.....	73

^a 100

The powder is divided into sizes according to diameter of grain, the sizes being separated and collected by sieves of different mesh. The sizes most usually offered for sale are called CC, C, F, FF, FFF, and FFFF. Of these CC represents the largest grains, about one-

^a A small percentage of water is included.

half inch in diameter, and FFFF represents the smallest grains, about one-sixteenth inch in diameter.

GASES AND PRESSURE PRODUCED ON EXPLOSION.

When blasting powder is ignited in a drill hole a rapid combustion takes place, and it is the pressure of the highly heated gases formed that disrupts the rock. It has been found that 150 liters (5.30 cu. ft.) of gas is produced from 454 grams (1 lb.) of black blasting powder, the gas being measured at normal temperature and pressure, 0° C., and 760 mm. When this volume is compared with the volume of permanent gases produced by the detonation of equal weights of nitroglycerin dynamites, it becomes evident that in a consideration of the energy developed by explosives there are other factors of more importance than the volume of permanent gases evolved.

At the instant of explosion the gases evolved are highly heated and tend to occupy a much greater volume than at normal temperature and pressure. Since the maximum theoretical temperature produced by the detonation of dynamite is much higher than that produced by the explosion of black blasting powder, the gases evolved on the detonation of dynamite are more highly heated and tend to expand more strongly than those evolved by black blasting powder.

TIME FACTOR.

The factor of time must also be taken into account in considering the power developed by explosives. The rate of detonation, explosion, or burning determines the characteristic effects of commercial explosives. This rate is the governing factor in judging relative efficiency, and offers the best basis for selecting explosives suitable for various mining conditions. The shattering effect of sudden pressure on a given substance is very different from that produced by an equal pressure applied slowly. The quicker the rate of the explosive reaction the more pronounced will be the shattering effect. The shattering effect of a commercial explosive depends on its rate of detonation.

During the conversion of an explosive into solid, liquid, and gaseous products the expansion of the gaseous products and the cooling effect of the walls of the drill hole or other heat-absorbent surroundings tends to reduce the temperature of the gases, so that the theoretical temperature or maximum pressure is never reached. The more nearly instantaneous the explosion reaction for a given explosive, all other conditions being equal, the greater is the volume of highly heated gases it produces in unit of time and the more violent is the effect it exerts.

The rate of burning of FF black blasting powder, as determined at the Pittsburgh testing station under conditions simulating those

that prevail when powder explodes in a drill hole, has been found to be 469 meters (1,538 feet) per second. This rate is slow compared with the rate of detonation of "ordinary" dynamites. Inasmuch as the gases from the combustion of black blasting powder form at such a relatively slow rate, the pressures produced are prolonged and there is a corresponding loss of heat and pressure from conduction and radiation. Black blasting powder is, therefore, best suited for work in which a gradual pushing or heaving effect is desired. In order to obtain the maximum efficiency of black blasting powder the charge must be well confined by suitable stemming. The most successful results are obtained when the drill holes are tamped to the mouth.

Black blasting powder is used in excavating cuts, quarrying soft rock or stone, and especially in quarries where large blocks of building stone are sought. In some work it is necessary to chamber or hollow out the bottom of the drill hole with dynamite or other suitable high explosive, and thus make a large cavity at the point where the powder can be placed to best advantage. When drill holes are enlarged in this way they become hot, hence they should not be loaded immediately after chambering, as the heat may explode the powder charge prematurely.

GRANULATED NITROGLYCERIN POWDERS.

The following composition is an example of a granulated nitroglycerin powder that is offered for sale in this country:

Composition of commercial granulated nitroglycerin powder.

Nitroglycerin.....	5.0
Combustible material ^a	35.0
Sodium nitrate.....	60.0
	100.0

The composition of the basic grains of granulated nitroglycerin powders is somewhat similar to that of black blasting powder. Instead of the nitrate and the combustible materials being thoroughly incorporated, these ingredients are heated to a temperature at which the resin and sulphur melt. The sticky mass formed is then granulated by cooling while being rubbed through a fine-mesh screen.

The grains produced in this way are hard and porous; they can be superficially coated or have their interstices filled with a small proportion of nitroglycerin. To insure the maximum efficiency of a granulated powder it is necessary to detonate the charge with a priming cartridge of dynamite. The nitroglycerin superficially held in the interstices and on the outside of the powder grains detonates, and thus accelerates the combustion of the grains. The

^a Consists of sulphur, coal, and resin.

rate of detonation of granulated powder has been found to be 1,018 meters (3,339 feet per second), or more than twice that of black blasting powder. Consequently, granulated powder is more effective and gives better results than black blasting powder in soft and seamy rock or in material that does not sufficiently confine the gases evolved.

"STRAIGHT" NITROGLYCERIN DYNAMITES.

The following compositions are examples of the "straight" nitroglycerin dynamites that are generally offered for sale in this country:

Compositions of "straight" nitroglycerin dynamites of various strengths.

Ingredients.	15 per cent.	20 per cent.	25 per cent.	30 per cent.	35 per cent.	40 per cent.	45 per cent.	50 per cent.	55 per cent.	60 per cent.
Nitroglycerin.....	15	20	25	30	35	40	45	50	55	60
Combustible material ^a	20	19	18	17	16	15	14	14	15	16
Sodium nitrate.....	64	60	56	52	48	44	40	35	29	23
Calcium or magnesium carbonate.....	1	1	1	1	1	1	1	1	1	1
	100	100	100	100	100	100	100	100	100	100

^a Consisting of wood pulp, flour, and sulphur for grades below 40 per cent; wood pulp only for other grades.

The rates of detonation of 30 per cent and 60 per cent "straight" nitroglycerin dynamites have been found, by tests at the Pittsburgh station, to be, respectively, 4,548 meters (14,920 feet) and 6,246 meters (20,490 feet) per second.

The "straight" nitroglycerin dynamites as a class develop greater disruptive force than any of the other commercial types of explosives tested, and for this reason they should be used, whenever the conditions permit, for producing shattering effects or for blasting very tough or hard materials.

LOW-FREEZING DYNAMITES.

If the "straight" nitroglycerin dynamites are found to be too violent for certain classes of work, the low-freezing dynamites or the ammonia dynamites, which have lower rates of detonation and hence less disruptive effect, may be used to advantage. The following table shows typical compositions of low-freezing dynamites:

Compositions of low-freezing dynamites of various strengths.

Ingredients.	30 per cent strength.	35 per cent strength.	40 per cent strength.	45 per cent strength.	50 per cent strength.	55 per cent strength.	60 per cent strength.
Nitroglycerin.....	23	26	30	34	38	41	45
Nitrosubstitution compounds...	7	9	10	11	12	14	15
Combustible material ^a	17	16	15	14	14	15	16
Sodium nitrate.....	52	48	44	40	35	29	23
Calcium or magnesium carbonate.....	1	1	1	1	1	1	1
	100	100	100	100	100	100	100

^a Composition similar to that in the "straight" nitroglycerin dynamites.

The low-freezing dynamites have the advantage of not freezing until exposed to a temperature of 35° F. or less, but, like all nitroglycerin explosives, after they become frozen they must be thawed before use in order to insure the most effective results.

AMMONIA DYNAMITES.

The ammonia dynamites, compared with the other dynamites, have the disadvantage of taking up moisture very readily, because ammonium nitrate is deliquescent, and care should be observed when they are stored or used in wet places.

The following table shows typical compositions of ammonia dynamites:

Compositions of ammonia dynamites of various strengths.

Ingredients.	30 per cent strength.	35 per cent strength.	40 per cent strength.	50 per cent strength.	60 per cent strength.
Nitroglycerin.....	15	20	22	27	35
Ammonium nitrate.....	15	15	20	25	30
Sodium nitrate.....	51	48	42	36	24
Combustible material <i>a</i>	18	16	15	11	10
Calcium carbonate or zinc oxide.....	1	1	1	1	1
	100	100	100	100	100

a Composition similar to that in the "straight" nitroglycerin dynamites of the grades below 40 per cent.

GELATIN DYNAMITES.

The gelatin dynamites have been used to a large extent in wet blasting, as in the removal of obstacles to navigation and in deep workings, and as a general rule are best suited for these purposes. In the manufacture of these dynamites the nitroglycerin is gelatinized by the addition of a small percentage of nitrocellulose. The jelly-like mass thus formed is impervious to water. By the addition of different percentages of suitable absorbents the various grades of these dynamites are made.

The following compositions are examples of gelatin dynamites generally offered for sale in this country:

Compositions of gelatin dynamites of various strengths.

Ingredients.	30 per cent strength.	35 per cent strength.	40 per cent strength.	50 per cent strength.	55 per cent strength.	60 per cent strength.	70 per cent strength.
Nitroglycerin.....	23.0	28.0	33.0	42.0	46.0	50.0	60.0
Nitrocellulose.....	0.7	0.9	1.0	1.5	1.7	1.9	2.4
Sodium nitrate.....	62.3	58.1	52.0	45.5	42.3	38.1	29.6
Combustible material <i>a</i>	13.0	12.0	13.0	10.0	9.0	9.0	7.0
Calcium carbonate.....	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

a Wood pulp is used in 60 and in 70 per cent strength gelatin dynamite. Sulphur, flour, wood pulp, and sometimes resin are used in other grades. Some manufacturers replace a small percentage of the nitroglycerin in these grades with an equal amount of ammonium nitrate. This replacement, however, offers little, if any, advantage other than reducing the cost of manufacture.

EXPLOSIVES USED IN MINING AND TUNNELING OPERATIONS.

It is generally recognized that in driving tunnels, sinking shafts, and in removing hard rock in metal mining, explosives having a high disruptive force are preferable. In work of this kind the cost of drilling holes is an important item. It has been found more economical to drill a few holes and to load them with an explosive of high disruptive force than to drill a number of holes and use weaker and cheaper explosives. It is important that explosives used in this class of work should produce the minimum amount of poisonous gases.

From what has been said about the composition and the characteristics of the different classes of explosives, it is evident that black blasting powder, granulated nitroglycerin powders, low-freezing dynamites, and ammonia dynamites would not be suitable or satisfactory for use in work of this kind, for they do not develop the requisite disruptive force; furthermore, these explosives, in common with the straight nitroglycerin dynamites, produce poisonous gases which vitiate the atmosphere of the working places.

PRODUCTS OF EXPLOSION.

At the Pittsburgh testing station the Bichel pressure gage,^a used for determining the theoretical maximum pressures developed by explosives, is also used for collecting the gaseous, liquid, and solid products of explosion. The same method is used in preparing the charge and firing as in determining the maximum pressures developed, except that the indicator mechanism then used is replaced by a pressure gage. After the charge has been fired, the gases are allowed to cool for 30 minutes, the pressure is recorded, and the volume of gases at standard temperature and pressure (0° C. and 760 mm.) is computed. A differential sample of the gases is then taken over mercury by allowing the gases to escape gradually from the gage. The results of tests of various classes of explosives are tabulated below. A charge of 200 grams of the explosive in its original wrapper was used in all tests, except with black blasting powder, which was fired in charges of 300 grams.

^a For a description of the Bichel gage, see Bull. 15, Bureau of Mines, p. 103.

Combustion products resulting from tests of explosives in thin paraffined paper wrappers.^a

[A. L. Hyde, analyst.]

Class and grade of explosive.	Electric detonator used.	Weight of products of combustion (grams).			Gaseous products (per cent by volume).							Solids (per cent).		Volume of gas (liters).
		Gaseous.	Solid.	Liquid.	Carbon dioxide.	Carbon monoxide.	Oxygen.	Hydrogen.	Methane.	Nitrogen.	Hydrogen sulphide.	Soluble.	Insoluble.	
30 per cent "straight" nitroglycerin dynamite.....	6	96.8	102.1	12.9	22.9	28.4	0.0	20.6	0.7	27.4		88.00	12.00	85.8
40 per cent "straight" nitroglycerin dynamite.....	6	107.4	87.1	12.4	27.3	26.9	.0	18.0	.4	27.4		86.73	13.27	88.5
50 per cent "straight" nitroglycerin dynamite.....	6	124.6	70.3	14.7	24.4	31.2	.0	20.7	.7	23.0		79.14	20.86	105.5
60 per cent "straight" nitroglycerin dynamite.....	6	143.5	49.6	11.9	22.2	34.6	.0	23.2	.8	19.2		68.53	31.47	128.9
60 per cent strength low-freezing dynamite.....	6	161.5	43.5	3.9	8.9	47.4	.0	31.0	.6	12.1		78.76	21.24	169.5
40 per cent strength ammonia dynamite.....	6	95.7	85.9	26.1	41.4	3.8	.0	3.1	.8	45.5	5.4	86.03	13.97	65.6
40 per cent strength gelatin dynamite ..	6	96.3	96.3	11.7	50.8	3.0	.0	1.8	.8	39.5	4.1	87.32	12.68	60.3
5 per cent granulated nitroglycerin powder b.....	6	115.5	93.6	8.3	51.3	2.7	.0	.9	.7	28.7	15.7	78.00	22.00	61.6
FFF black blasting powder.....	(c)	154.4	126.9	4.1	49.7	10.8	.0	1.8	.6	28.4	8.7	91.20	8.80	67.8

^a The explosives named in this table are not of the same formulas as those in the tables on pages 8 and 9.

^b Primer of 40 per cent "straight" nitroglycerin dynamite, representing 10 per cent by weight of the charge, was used, but the gases evolved by the dynamite were deducted in the computations of the volume of gas (liters).

^c Black-powder igniter used.

The test results tabulated above show that gelatin dynamites on detonation produce the smallest percentage of poisonous gases (carbon monoxide and hydrogen sulphide). However, even that class of explosives is far from being satisfactory in this respect. Nevertheless, the gelatin dynamites are largely used in this country in metal-mining and in tunneling operations.

The ventilation in many metal mines and tunnels is defective, and yet the use of large quantities of explosives is necessary. Numerous accidents in deep workings have occurred from air vitiation caused by the poisonous gases evolved by detonating explosives. In one of the large western engineering projects 9 men recently were killed by the poisonous gases produced on the explosion of 40 per cent strength gelatin dynamite.

Soon after this accident the Bureau of Mines began studies of the noxious gases evolved on the detonation of explosives in order to discover whether the composition of explosives could be improved so as to increase safety in mining operations.

FORMULA FOR A MINE EXPLOSIVE.

From the foregoing statement it is evident that the only two classes of available explosives that develop the disruptive force required in removing hard rock in metal-mining and tunneling work are "straight" nitroglycerin dynamites and gelatin dynamites. To construct well-balanced formulas for the "straight" nitroglycerin dynamites it is necessary to reduce the percentage of combustible materials in order that there may not be a deficiency of oxygen. This reduction can be accomplished by replacing the wood pulp in the higher grades of these explosives with some inert material having a great absorbing capacity, such as magnesium carbonate or kieselguhr (infusorial earth), but as this method materially decreases the efficiency of the explosive by reducing the quantity of active matter, it was thought advisable to conduct experiments with gelatin dynamites, which do not require combustible material for absorbing the nitroglycerin.

Several samples of 40 per cent strength gelatin dynamite were procured from different manufacturers. All these samples produced poisonous gases on detonation, the percentage of carbon monoxide varying from 3 to 5.7 per cent and of hydrogen sulphide from 0.7 to 4.1 per cent.

The formulas for gelatin dynamites given on page 8 seem to provide for sufficient oxygen in the sodium nitrate to completely oxidize the combustible materials, and for this reason all the formulas are said to be well balanced. However, the gage tests showed that quantities of hydrogen sulphide were evolved on detonation and remained in the permanent gases. The sulphur used in the gelatin dynamites was held responsible for this result, and its elimination as an ingredient was necessary. The result of further investigations showed that paper wrappers heavily coated with paraffin, used in connection with the explosive and representing a comparatively large percentage by weight of combustible material, had not been given due consideration by the manufacturers of explosives. It was believed that by slightly increasing the percentage of the sodium nitrate sufficient oxygen would be provided to completely oxidize the hydrogen and carbon contents of the paper wrapper.

As a result of the investigations a quantity of 40 per cent strength gelatin dynamite was manufactured according to the following formula:

Special formula for 40 per cent strength gelatin dynamite.

Nitroglycerin.....	33
Nitrocellulose.....	1
Sodium nitrate.....	54
Combustible material ^a	11
Calcium carbonate.....	1

100

^a Flour.

The products of combustion were collected in the gage, 200 grams of the explosive in the original wrapper being used under the same conditions as in previous tests. The wrapper, like those of explosives previously tested, was paper coated with paraffin. The results of tests made with this explosive are shown in the following tables:

Combustion products resulting from tests of special 40 per cent strength gelatin dynamite.

[Analyst A. L. Hyde.]

WEIGHT OF PRODUCTS, GRAMS.

Gaseous.....	85.5
Solids.....	102.3
Liquid.....	13.2

GASEOUS PRODUCTS, PER CENT BY VOLUME.

Carbon dioxide.....	51.0
Carbon monoxide.....	.0
Oxygen.....	.9
Hydrogen.....	.0
Methane.....	.7
Nitrogen.....	47.4
Hydrogen sulphide.....	.0
	100.0

SOLIDS, PER CENT.

Soluble.....	92.10
Insoluble.....	7.90
	100.00

It will be noted that the above modified formula for 40 per cent strength gelatin dynamite on detonation in metal gages did not evolve poisonous gases. However, the question was raised as to whether such gases might not be evolved when large quantities of the explosive were detonated under actual mining conditions. It was then decided to supplement the gage tests by tests in mines.

MINE TESTS.

In taking samples of mine air after blasts with the older dynamites it was necessary for the investigators to use a breathing apparatus. The samples were taken by air displacement by means of small bellows, which was emptied and filled fifty times.

TESTS IN A LIMESTONE MINE.

The first experiments were carried out in a limestone mine at West Winfield, Pa. W. O. Snelling, consulting chemist of the Bureau of Mines, cooperated in the experiments. As the limestone in the mine mentioned was mined by the room-and-pillar method, the pro-

cedure followed was to shoot the rock "off the solid" with four or more shots, depending on the width of the face worked (figs. 1 and 2).

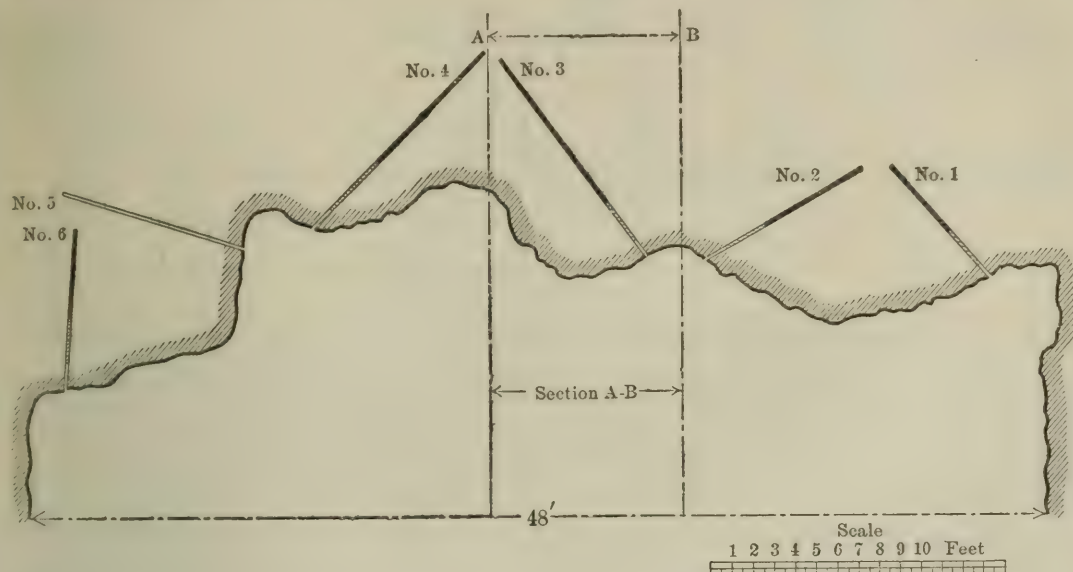


FIGURE 1.—Arrangement of drill holes in experiments in a limestone mine. Plan.

This necessitated the use of different quantities of explosives in the different working places. No. 6 electric detonators were used, and

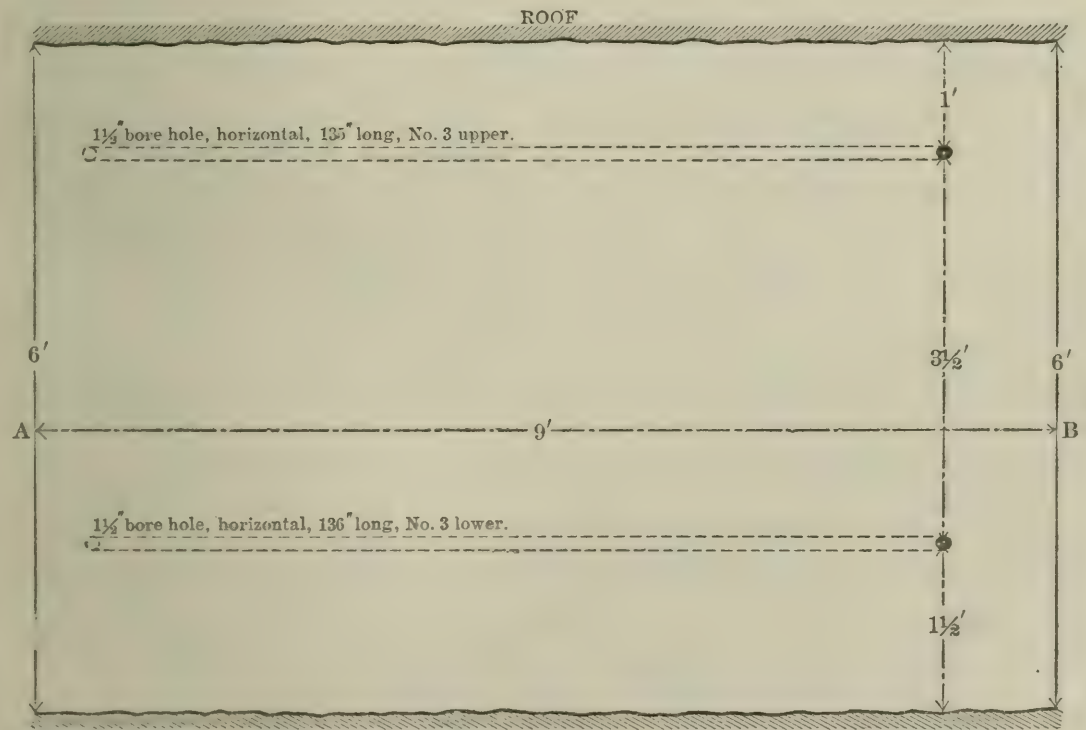


FIGURE 2.—Arrangement of drill holes in experiments in a limestone mine. Position of holes in front elevation A-B of face.

the shots were connected in series and fired at one time. The results of the tests are tabulated on the page following.

Results of tests with different classes of explosives in a limestone mine at West Winfield, Pa.

Class and grade of explosive used.	Quantity of explosive used (pounds).	Location of blast.	Where sample was taken.	Time sample was taken.	Analyses of mine-atmosphere samples. ^a						
					CO ₂	O ₂	CO	N ₂	H ₂ S	H ₂	CH ₄ and C ₂ H ₄
40 per cent strength gelatin dynamite.	103.5	Room 5 off "A" cross entry.	At face of room near roof.	Immediately after firing blast.	2.67	19.53	0.25	77.44	0.0	0.11	0.0
				5 minutes after blast.	1.75	19.73	.12	78.34	.0	.06	.0
				10 minutes after blast.	.43	20.31	.10	79.11	.0	.05	.0
Do.....	39.5	Room 1 off 4th cross-cut.	...do.....	Immediately after firing blast.	.25	20.38	.05	79.29	.0	.03	.0
				5 minutes after blast.	.15	20.70	.0	79.15	.0	.0	.0
				10 minutes after blast.	.13	20.54	.0	79.33	.0	.0	.0
New 40 per cent strength gelatin dynamite.	28.5	Room 10 off "B" cross-cut.	...do.....	Immediately after firing blast.	.37	20.43	.0	79.20	.0	.0	.0
				10 minutes after blast.	.10	20.80	.0	79.10	.0	.0	.0
				12 minutes after blast.	1.65	20.40	.40	78.35	.0	.20	.0
40 per cent "straight" nitroglycerin dynamite.	22.0	"D" cross-cut.	...do.....	Immediately after firing blast.	.27	20.45	.15	78.87	.0	.06	.0
				2 minutes after blast.	.08	20.80	.0	79.12	.0	.0	.0
				12 minutes after blast.	.08	20.80	.0	79.12	.0	.0	.0

^a G. A. Burrell, analyst.

TESTS IN A ZINC MINE.

The second series of experiments was carried out in a zinc mine at Franklin Furnace, N. J. W. O. Snelling, consulting chemist of the bureau, cooperated in the tests. The headings in which the tests were made averaged about 5 feet in width and 7 feet in height. In driving these headings a "21-hole cut" was used (figs. 3 and 4). In such a cut the first shot, hole *a*, is fired in the center of the face. It is known as a "burning" shot and is not intended to blast out any material but merely to form a crack in the middle of the face or so to disintegrate the rock that when the first round of shots, holes *b* and *c*, is fired the material will be blasted out. Holes *d* and *e* were not loaded. The method of loading and firing the second, third, and fourth rounds of shots is similar to that generally followed in metal mines.

The holes for the second round of shots were spaced as shown in figure 3, the holes for this round being designated *f*, *g*, *h*, and *i*; the holes for the third round of shots were spaced in accordance with those lettered *o*, *p*, *q*, *r*, *s*, *t*, and *u* in the figure, and the holes for the fourth round were spaced in accordance with those lettered *j*, *k*, *l*, *m*, and *n* in the figure. The depth of the holes, the number of cartridges of explosives used in each, the length of drill hole which they occupied, the length of drill hole occupied by the stemming, and the free portion of the drill hole (that portion of the drill hole that is in front of the stemming and not occupied—see fig. 4) for the third round of holes shot with the new 40 per cent strength gelatin dynamite are indicated in figures 3 and 4 and in the table following.

Details of tests of explosives in a zinc mine at Franklin Furnace, N. J.

Hole. ^a	Number of cartridges.	Depth of drill hole.	Explosive occupied—	Stemming occupied—	Free portion of drill hole.
		Inches.	Inches.	Inches.	Inches.
<i>o</i>	6	79	44½	3½	31
<i>p</i>	5	76	41	10	25
<i>q</i>	8	87	52	8	27
<i>r</i>	6	80	46	9	25
<i>s</i>	7	86	54	5	27
<i>t</i>	7	89	51	12	26
<i>u</i>	8	87	59	8	20

^a See figure 3.

Attention is called to the comparatively small amounts of stemming used in front of the charge as compared with the large amounts of explosives used, although the charging was done by an experienced man and according to the usual practice in that mine. An investigation of the effect of stemming on the efficiency of explosives which is now in progress by the bureau^a indicates that the amount of stemming used in these shots was not sufficient.

The results of the experiments in the zinc mine are shown below:

Results of tests with different classes of explosives in a zinc mine at Franklin Furnace, N. J.

Class and grade of explosive used.	Quantity of explosive used (pounds).	Location of blast.	Where sample was taken.	Time sample was taken.	Analyses of mine-atmosphere samples. ^b						
					CO ₂	O ₂	CO	N ₂	H ₂ S	H ₂	CH ₄ and C ₂ H ₄
New 40 per cent strength gelatin dynamite.	18.4	400-foot level, 500 crosscut east, third round of holes.	4 feet from face, 5 feet from floor.	2 minutes after firing blast.	1.80	20.20	0.0	78.00	0.0	0.00	0.00
	32.0	Same (4th round of holes).	do	do	1.25	20.30	.0	78.45	.0	.00	.00
40 per cent strength ammonia dynamite.	25.6	450-foot level, 800 crosscut, third round of holes.	do	do	.65	20.46	.05	78.84	.0	.00	.00
			do	do	4.45	18.56	.09	76.90	.0	.00	.00
40 per cent "straight" nitroglycerin dynamite.	12.3	Same (4th round of holes).	68 feet from face, 5 feet from floor.	3 minutes after firing blast.	.59	20.19	.00	79.27	.0	.00	.00
	25.0	450-foot level, north heading, second round of holes.	4 feet from face, 5 feet from floor.	2 minutes after firing blast.	1.76	20.17	.11	77.92	.0	.04	.00
			35 feet from face, 5 feet from floor.	4 minutes after firing blast.	.98	20.50	.0	78.48	.0	.04	.00

^a See Technical Paper 17, Bureau of Mines.

^b G. A. Burrell, analyst.

CONCLUSIONS.

The mine tests, although of small scope, confirmed, with a few exceptions, the tests made in the pressure gage. The odor of hydrogen sulphide was noticeable immediately after firing some of the explosives containing sulphur, but the chemical analyses of the mine-air

samples failed to disclose the presence of an appreciable quantity of this gas. Several days intervened between the taking of the samples in the mine and the chemical examinations made of them, and it is possible that if minute quantities of hydrogen sulphide were collected in any of the samples, they were decomposed by standing so long. It is worthy of note that in all the tests the explosives were completely detonated and there was no formation of nitrogen oxides.

The results of the experiments indicate that all gelatin dynamites should be made with an oxygen excess sufficient to completely oxidize all combustible materials present, including the wrappers; furthermore, the tests show that when this class of explosive is properly and completely detonated the proportion of harmful gases evolved is reduced to a minimum. However, it should be remembered that proper conditions do not exist if there has been any chemical or physical change in the explosive or if it is fired under conditions that cause burning or incomplete detonation. When the explosive has aged to such an extent as to materially decrease its sensitiveness, when weak detonators are used, or when the explosive is used in a frozen or partly frozen condition, a greater quantity of poisonous gases is evolved.

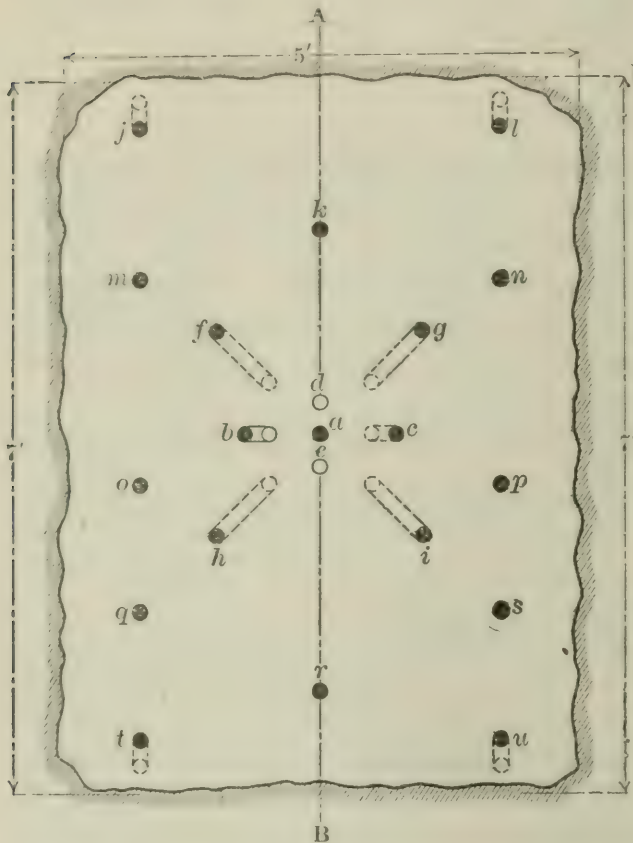


FIGURE 3.—Arrangement of drill holes in experiments in a zinc mine. Front view of face.

GASES EVOLVED IN THE BURNING OF EXPLOSIVES.

To determine the percentage of poisonous gases evolved when high explosives burn, a charge of $54\frac{1}{2}$ grams of the "ordinary" 40 per cent strength gelatin dynamite, including paper wrapper, was ignited by

an electric igniter in the pressure gage under atmospheric pressure. The gage was closed except that the indicator-connection hole was left

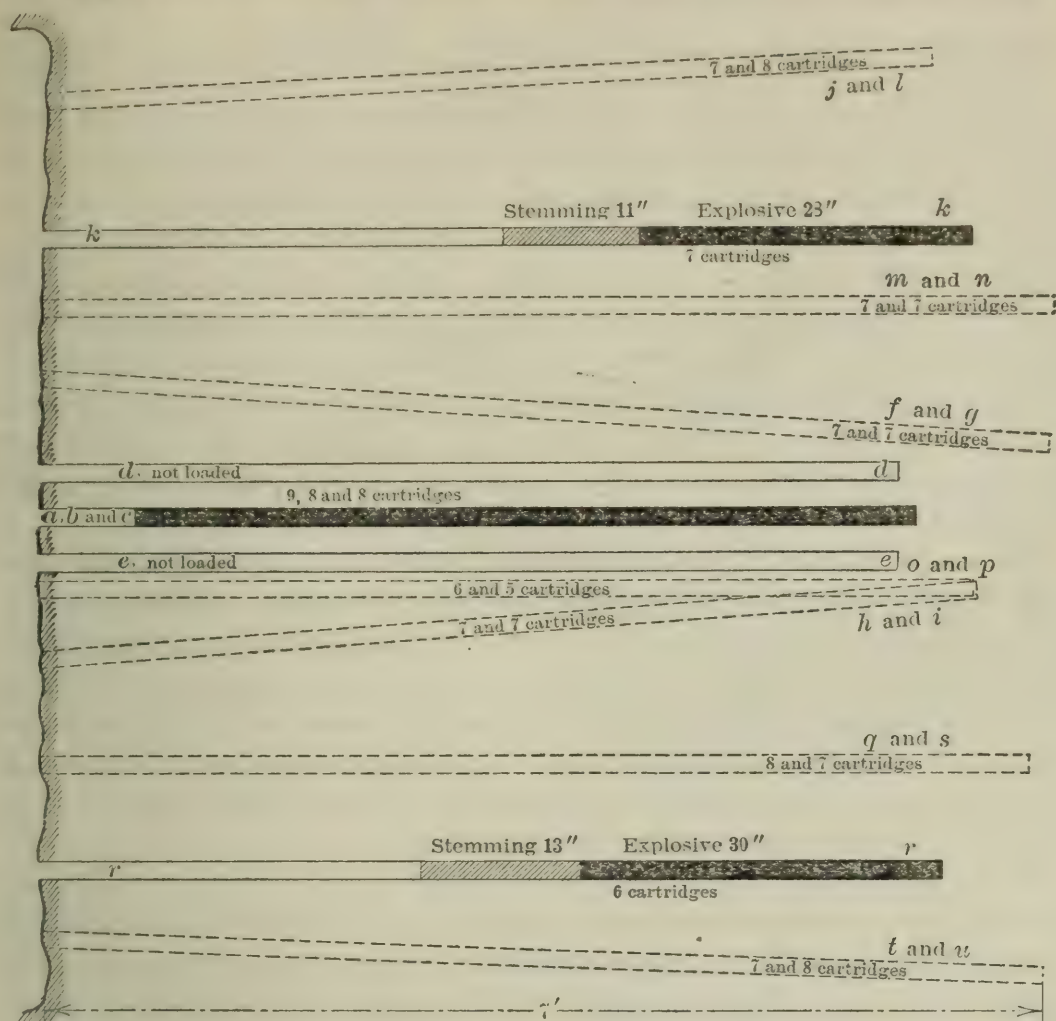


FIGURE 4.—Arrangement of drill holes in experiments in a zinc mine. Section through face.

open for the collection of samples of the gaseous products. The analysis of these products is given in the following tabulation:

Analysis of gaseous products of combustion.

[A. L. Hyde, analyst.]	
Carbon dioxide	19.4
Oxygen.....	.0
Carbon monoxide.....	13.7
Nitric oxide (NO)	11.3
Hydrogen.....	.4
Methane.....	1.4
Nitrogen.....	53.2
Nitrogen peroxide (NO ₂).....	.6
	100.0

It is to be noted that the percentages of poisonous gases evolved, 13.7 per cent of carbon monoxide and 11.9 per cent of nitrogen oxides, show an increase of 18.5 per cent over the percentages from the same explosive when completely detonated in gage tests. It is reasonable

to suppose that the results would be the same if the explosive burned and did not detonate under actual mining conditions in the blasting of rock and similar materials.

CHEMICALS PROPOSED FOR NEUTRALIZING POISONOUS GASES.

In order to neutralize or to prevent the formation of poisonous gases evolved on the detonation of explosives when used in blasting operations, the use of several compounds has been proposed. The compounds proposed consist of oxygen-carrying salts or of mixtures of alkaline carbonates or bicarbonates, camphor (gum), etc. They have been offered to the trade packed in cardboard cartridge shells weighing about 1 ounce each. It is claimed by the manufacturers of these compounds that if one cartridge thereof be placed in the back of a drill hole before loading a charge of $1\frac{1}{2}$ pounds of 40 per cent dynamite, its action when the explosion occurs will prevent the formation of all poisonous gases or will neutralize them.

The use of compounds that have oxygen-carrying salts might offer some advantages with explosives deficient in oxygen. However, such compounds probably could not be used with explosives designed for use in coal mines. If the compounds entered into the explosive reaction and thus prevented the formation of carbon monoxide, the increased volume of carbon dioxide formed would probably be accompanied by a larger evolution of heat and the higher flame temperature might eliminate the safety features of the explosive.

Tests in coal mines have shown that coal drillings in a shot hole enter into the explosive reaction. Moreover, the gaseous products of blasts in coal contain, for any explosive, more carbon monoxide and less carbon dioxide than the products of explosion tests in metal gages.

The following tabulation gives the results of analyses of the gases produced from black blasting powder when fired under the usual conditions in a metal gage, and also under actual coal-mining conditions:

Results of analyses of gaseous products of explosion of black blasting powder.

Constituents.	Gage tests. ^a		Mine tests. ^b
	Cartridges without paper wrapper.	Cartridges with paper wrapper.	Cartridges with paper wrapper.
Carbon dioxide.....	49.7	44.9	19.2
Carbon monoxide.....	10.8	13.2	28.2
Oxygen.....	.0	.0	.0
Hydrogen.....	1.8	4.2	10.0
Methane.....	.6	.4	.4
Nitrogen.....	28.4	27.3	35.4
Hydrogen sulphide.....	8.7	10.0	6.8
	100.0	100.0	100.0

^a A. L. Hyde, analyst.

^b G. A. Burrell, analyst. The samples were taken from crevices caused by the explosion. As the crevice gases are diluted with air, the mine samples, for comparison with the gage-test results, were computed on an air-free basis; that is, the oxygen content was eliminated and a corresponding percentage of nitrogen (according to the proportion in normal air) was subtracted. Also, the proportion of methane distilled or pressed out of the coal was subtracted to make the methane percentage correspond to that of the gage samples.

The results tabulated indicate that any chemical containing sufficient oxygen, if associated with the explosive charge in the drill hole in a similar way, would tend to reduce the formation of carbon monoxide and, accordingly, minimize some of the poisonous gases formed. Obviously, if the chemical could be intimately associated with the ingredients of the explosive, a more complete reaction would result, but as this procedure is impracticable in loading charges of explosives and as the user of explosives would not know the exact amount to use with different brands of explosives, the value of using chemicals of this kind in mining operations is questionable.

It has been stated that explosives can be manufactured for tunneling and for metal mining that do not produce poisonous gases when completely detonated. Complete combustion can be assured if the manufacturers use a quantity of the oxygen-carrying salts sufficient to oxidize completely all the combustible ingredients of the explosives, including paper wrappers. Explosives so constituted would not require the use of auxiliary materials.

Compounds containing alkaline carbonates, bicarbonates, camphor (gum), etc., proposed for use in preventing the formation of poisonous gases are equally unsatisfactory. It has been pointed out that explosives on burning produce nitrogen oxides and that the presence of alkaline carbonates or bicarbonates may tend to neutralize to some extent the poisonous gases. However, as the nitrogen oxides are not formed when the explosives are completely detonated and as the complete detonation of explosives can be brought about by the use of a detonator of the proper kind, it is unnecessary to resort to the use of these compounds. When using compounds of this kind the miner has often been misled by the pleasant aromatic odor often noticeable in the working places after a blast. A series of tests with the compounds was undertaken to determine whether their use would render less noxious the gaseous products of an explosion of dynamite.

The compound used in the tests was a fine crystalline powder packed in a cardboard cartridge shell which was crimped at each end over a cardboard wad. The average weight of the ingredients of each cartridge was 13.6 grams, the cardboard cartridge shell or wrapper weighing 9.6 grams. The materials used were said to be ammonium carbonate, sodium bicarbonate, chloride of lime, and gum camphor. The result of a chemical analysis of the compound, as used, was as follows:

Results of analysis of a neutralizing compound.

[C. G. Storm, analyst.]

Moisture.....	4. 01
Camphor gum.....	9. 33
Sodium bicarbonate.....	14. 62
Sodium chloride.....	9. 30
Ammonium carbonate.....	42. 88
Calcium carbonate.....	19. 86

100. 00

It was evident that certain reactions had taken place after the compound had been made. The chlorine of the chloride of lime had been liberated and was combined as sodium chloride. There was evidence that other reactions had taken place, but they were not believed to be such as to have affected materially the value of the composition for the purpose intended. In the tests various mixtures of the compound and 40 per cent "straight" nitroglycerin dynamite were used. The prepared charges were fired by No. 6 electric detonators in a metal gage from which practically all of the air had been pumped by a vacuum pump. After the gases within the gage had cooled, their temperature and pressure were read, their weight in grams and their volume in liters being then computed. A differential sample of the gaseous products of combustion was procured by collecting the gas as it escaped through the gage valve. The percentage by volume of the gaseous products of combustion and the quantity in liters of each of the gases evolved are given in the following table in which, for convenience in reporting the results, the tests are designated A, B, C, D, E, and F.

Results of tests of mixtures of dynamite and a neutralizing compound.

Test designation.	Weight of original wrapper per 100 grams of explosive ingredient.	Weight of compound used, including cardboard wrapper.	Total weight of charge.	Gaseous products of combustion, per cent by volume. ^a					
				CO ₂ .	O ₂ .	CO.	H ₂ .	CH ₄ .	N ₂ .
A.....	Grams. None.	Grams. None.	Grams. ^b 206.0	51.4	0.0	5.0	2.2	0.3	41.1
B.....	6.2	None.	^c 212.4	27.3	.0	26.9	18.0	.4	27.4
C ^d	6.2	7.2	^c 219.6	25.6	.0	28.2	18.9	.5	26.8
D ^d	6.2	23.8	^c 236.2	20.7	.0	31.5	25.0	.7	22.1
E ^e	6.2	7.2	^c 219.6	24.5	.0	28.5	20.4	.6	26.0
F ^f	6.2	4.2	^c 217.1	28.2	.0	25.5	17.7	.4	28.2

COMPUTATIONS BASED ON THE ABOVE RESULTS OF TESTS.

Test designation.	Weight of gas.	Volume of gas.	Volume of the gaseous products of combustion.					
			CO ₂ .	O ₂ .	CO.	H ₂ .	CH ₄ .	N ₂ .
A.....	Grams. 88.4	Liters. 55.6	Liters. 28.6	Liters. 0.0	Liters. 2.8	Liters. 1.2	Liters. 0.2	Liters. 22.9
B.....	107.4	87.0	23.8	.0	23.4	15.7	.3	23.8
C.....	111.1	91.7	23.5	.0	25.9	17.3	.5	24.6
D.....	124.0	112.2	23.2	.0	35.3	28.0	.8	24.8
E.....	108.2	91.3	22.4	.0	26.0	18.6	.5	23.7
F.....	108.8	87.4	24.6	.0	22.3	15.5	.3	24.6

^a A. L. Hyde, analyst.
^b Includes the 6-gram tinfoil wrapper.
^c With the original paper wrapper weighing 12.4 grams.
^d The cardboard wrapper of the compound was cut into small pieces and together with the compound was thoroughly mixed with the explosive ingredients.
^e To simulate average mining conditions, 7.2 grams of the compound, including the cardboard wrapper, was placed at the end of the explosive charge opposite the end in which the electric detonator was placed.
^f Made under the same conditions present in test E, except that the cardboard wrapper of the compound was replaced by a tinfoil wrapper weighing 0.5 gram.

Logical conclusions from the results of the tests are that compounds of this kind offer no advantage in preventing or neutralizing the poisonous gases evolved on the detonation of explosives; that the heavy cardboard wrapper used is responsible for an increase in the percentage of carbon monoxide formed, and that if such a compound is used as recommended by the manufacturer its use will produce a greater rather than a less amount of poisonous gases.

EXPLOSIVES FOR USE IN GASEOUS OR DUSTY COAL MINES.

PERMISSIBLE EXPLOSIVES.

Explosives suitable for use in gaseous or dusty coal mines differ greatly from those previously mentioned in this paper. In addition to possessing the requisite qualities of strength and efficiency in breaking down coal, they should be of such a composition as to produce, on explosion, a relatively short flame of relatively low temperature.

To accomplish this result, free water or an excess of carbon are added to some of the coal-mining explosives, and others contain flame-reducing salts. To determine whether an explosive is satisfactory requires careful testing. To carry out such tests the Bureau of Mines has installed at its Pittsburgh testing station suitable equipment, including a large steel cylinder or gallery which can be filled with fire damp or coal dust and air in any desired proportion.

Explosives that pass certain tests and that are used in accordance with the conditions prescribed by the bureau are called permissible explosives and are recommended for use in coal mines.

The underlying reasons why one explosive passes and another fails when tested in the presence of gas and dust have been investigated at the Pittsburgh testing station. The results of the researches, especially those on explosives that failed to pass the prescribed tests, have been reported to the manufacturers, who have in nearly all cases so changed and perfected their explosives that later when new explosives were submitted all the requirements of the bureau have been successfully met. The results of tests indicate that every explosive if fired in very large quantities will cause ignition of gas and coal-dust mixtures. An arbitrary charge, $1\frac{1}{2}$ pounds, has been established as the quantity of explosive to be used in making tests, and all explosives in order to be placed on the permissible list must pass the gas-and-dust test with this charge. A charge of $1\frac{1}{2}$ pounds per drill hole should never be exceeded in practice. In good mining practice the charge need not exceed 1 pound, an amount that provides a greater factor of safety.

In order to ignite inflammable gas and coal-dust mixtures a certain temperature, acting through a certain length of time, is required. Furthermore, the flame temperature of all explosives on detonation

exceeds the ignition temperature of inflammable gas-and-dust mixtures, but fortunately the flame of the permissible explosives, when properly detonated, is of such short duration that the inflammable mixtures are not ignited. It is evident that any factor that increases the duration of the flame temperature of a permissible explosive, such as the use of a weak detonator or the use of any explosive in ways not in accordance with those prescribed by the Bureau of Mines, may increase the danger in its use.

Permissible explosives are now being used in every coal-mining State in the Union. In 1909 there was 8,592,000 pounds of permissible explosives used in this country. In 1910 the amount used reached 11,900,000 pounds, and in 1911 the amount aggregated 13,428,000 pounds.

EXPLOSIVES USED IN SUBMARINE OPERATIONS.

At the request of T. P. Roberts, assistant United States engineer, the explosives section of the bureau began an investigation to determine the cause of failures of certain shots in December, 1911, in connection with the blasting of rock in the bottom of the Monongahela River at Lock No. 1, Pittsburgh, Pa.

METHOD OF BLASTING FOLLOWED AT LOCK NO. 1, MONONGAHELA RIVER.

The procedure followed was found to be similar to that ordinarily employed in submarine excavating. A drill boat was moored over the rock by means of adjustable legs and by mooring lines attached to the shore, and the holes were drilled in the underlying rock, a hard shale, by 2½-inch steel drills guided by long iron pipes 4 inches in diameter. On December 19, 1911, the depth of the water where the work was being conducted was 10 to 13 feet, depending on the elevation of the bottom of the river. At the time of the failures reported the stage of the river was lower. The sediment and drillings that accumulated in the 4-inch pipes during drilling were removed at intervals by means of an iron gooseneck pipe 1 inch in diameter. After the holes had been drilled to the required depth they were loaded with 40 per cent low-freezing dynamite by lowering charges through the 4-inch pipes. Three to five 1½ by 8 inch cartridges were generally used in each hole; the last stick was made into a primer containing one No. 6 electric detonator with 12-foot wires. Tallow was used to seal the cartridges in order to prevent the absorption of water by the explosives. All of the splicing of the legs of the detonators to each other and to the leading wires was well insulated. After the holes, usually 13 for a blast, had been charged, the iron pipes were carefully removed and the wires connected in series. The drill boat was then floated downstream to a safe position and the leading wires were con-

nected to a No. 3 push-down, two-pole firing machine. Before firing, the explosives and detonators remained for one-half to one hour in the water, the temperature of which at the time of inspection was 1° C. (34° F.).

It was stated that during the work of excavating, 286 holes had been fired and 5 failures had occurred, 2 in one set and 3 in another. The first failure occurred on December 6. A set of 13 holes had been loaded, but the seventh and tenth holes misfired when the blast was made. The charging had progressed from holes 1 to 13, and it was stated that the explosive in hole No. 1 was not in the water over 45 minutes. One of the electric detonators was recovered intact, and it was thought the misfire might have been due to an imperfection in the detonator wire, but when connected to and fired by the No. 3 firing machine it detonated completely. The other detonator was not recovered.

The second failure occurred on December 15, when a set of holes similar to those previously described was fired. In this instance holes 11, 12, and 13 misfired. All the detonators were recovered and only one failed to fire when retested. This detonator was delivered to the testing station for examination. The samples of 40 per cent low-freezing dynamite representing the last three shipments were also procured for examination and test purposes. It was noted at the time of inspection that the shot firer in operating the No. 3 firing machine used only one hand to push down the ratchet bar and did not push it down in that quick and forcible manner requisite for producing the maximum speed of the revolving armature.

TESTS OF ELECTRIC DETONATORS.

The first series of tests of electric detonators at the Pittsburgh testing station was made by connecting 30 No. 6 electric detonators in series and firing them with a No. 3 push-down two-pole firing machine. The ratchet bar was pushed down with different degrees of speed. In the two tests made, simulating the method used at Lock No. 1, there were 10 misfires in the first trial and 11 in the second. Two other tests were then made by pushing the ratchet bar down with both hands quickly and forcibly, especially during the last part of the stroke. In both trials all detonators were fired. As the amount of current generated by any firing machine of this type depends upon the speed of the revolving armature it is evident that the misfires at Lock No. 1 were partly due to the improper method followed in operating the No. 3 firing machine. These machines are so made as to store up the current during the stroke until just as the stroke is ended, when the entire current that has gathered is discharged through the leading wires.

It has been found from results of tests that the resistances of the platinum-wire bridges in certain detonators of the same grade and make vary from 0.7 to 1.0 ohm and that the electric detonators that misfire are usually those having low resistance. It has been generally considered that the loss of current that may occur by short-circuiting through wet ground or water is largely responsible for misfires when electric detonators are fired in series, but the tests made at the testing station indicate that the variation in the cross-sectional area of the platinum bridges within the detonators is a factor of greater importance. It can not be assumed with certainty, however, that a platinum

bridge having a high resistance can be fired with less current than one having a low resistance, because with a given current the maximum temperature of a bridge depends upon its minimum cross-sectional area only; the resistance varies not only inversely as the cross-sectional area of the bridge, but also directly as its length. An inspection of several bridges disclosed the fact that the length of the bridge did vary slightly, usually because of the encroachment of the solder on the platinum bridge.

Great care was necessary then in selecting detonators, and the assumption that the average detonator of high resistance would have a long bridge of relative small cross-sectional area, and the average detonator of low resistance would have a short bridge of relatively large cross-sectional area holds.

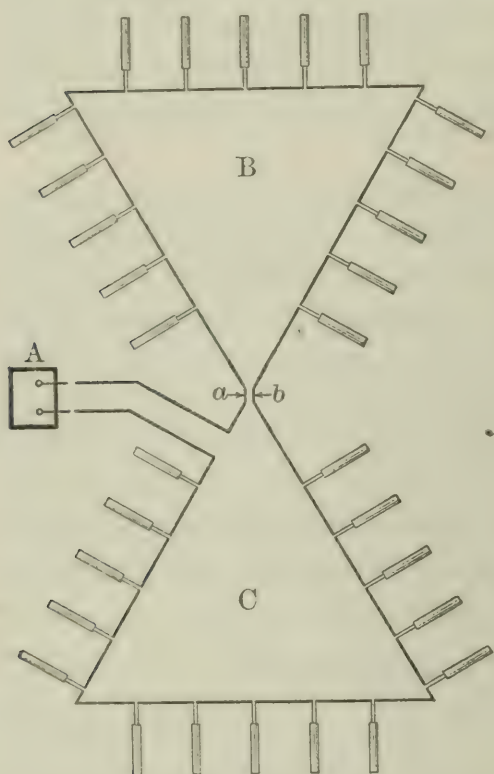


FIGURE 5.—Arrangement of electric detonators to determine whether a shunt of river water affected their detonation. A, firing machine; B, detonators of high resistance; C, detonators of low resistance; *a, b*, uninsulated wires.

For one test the resistance of 152 detonators was determined. Thirty of these were selected, 15 having the highest and 15 the lowest resistance. The resistances in ohms were as follows, the resistance of the detonators that failed being italicised: 0.90, 0.90, *0.90*, 0.91, 0.91, 0.91, 0.92, 0.92, *0.93*, 0.94, 0.95, 0.95, 0.95, 0.96, 0.96, and *0.72*, *0.73*, *0.76*, *0.77*, 0.77, 0.78, 0.78, *0.79*, *0.79*, 0.79, 0.79, 0.80, 0.80, 0.80, 0.81.

The 30 detonators were connected in series (fig. 5) and in order that the effect of a possible loss of current through river water might be determined a shunt of river water at 15° C. (59° F.) was arranged between the two terminals (1 inch apart) of the 15 detonators having

the high resistances (B, fig. 5.). An attempt was made to fire them with a No. 3 firing machine (A, fig. 5) operated at about half speed in order that the current passing through the bridges would fire some but not all of the detonators. If the conductivity of the water was great enough it was to be expected that the current passing through the 15 detonators of high resistance would not suffice to fire any of them; however, if the conductivity of the water was small enough it was to be expected that the following conditions would prevail:

1. That the average resistance of the detonators that failed would be less than that of those fired;
2. That the average resistance of the detonators of high resistance that failed would be less than that of those fired;
3. That the average resistance of the detonators of low resistance that failed would be less than that of those fired.

The actual results of the test may be expressed by detailing the averages corresponding to those mentioned above. These averages are presented below.

Average resistances of electric detonators tested.

	Ohms.
7 that failed.....	0.804
23 that fired.....	.868
2 of high resistance that failed.....	.915
13 of high resistance that fired.....	.929
5 of low resistance that failed.....	.760
10 of low resistance that fired.....	.788

Other similar tests confirmed in every particular the test outlined.

The results of these tests ^a showed that fewer failures occurred with the electric detonators having high resistance even when means were provided, as stated above, for introducing short-circuiting. It is unfortunate that the manufacturers of electric detonators can not supply platinum bridges having a more uniform cross-sectional area, but these unavoidable defects in bridges emphasize the importance of providing firing machines of adequate capacity and of operating them in such a manner that they will yield their maximum energy.

The electric detonator that failed on retest at Lock No. 1 was examined at the testing station by carefully opening the detonator in such a manner as to separate the sulphur plug from the copper capsule. The guncotton usually placed around the platinum bridge was slightly moist, a condition that would account for the failure of the fulminate charge to detonate. As previously stated, the three other detonators failed for the reason that when they were used the current passed through them was not strong enough to cause them to

^a A more extended study of the efficiency of electric detonators and firing machines is now in progress by the bureau.

fire, probably because of their low resistance. One detonator was not recovered and this was the only failure that could in any way be attributed to the explosive.

TESTS OF EXPLOSIVES.

A physical and chemical examination was made of each of the three samples of dynamite submitted. They were found to be remarkably uniform in composition. The nitroglycerin content of the dynamite was equal to that usually offered for sale in this country as 40 per cent low-freezing dynamite. However, it is to be noted, that all of the samples contained about 5 per cent of sodium chloride, which substance is well known to cause the reduction of flame temperature on detonation of an explosive and hence causes a material reduction of the energy developed. The results of tests are given in the following tabulation:

Results of tests of three explosives^a used in submarine operations.

PHYSICAL EXAMINATION.

Details observed.	Sample No. 1.	Sample No. 2.	Sample No. 3.
Length of cartridge, inches.....	8	8	8
Diameter of cartridge, inches.....	1 $\frac{1}{4}$	1 $\frac{1}{4}$	1 $\frac{1}{4}$
Weight, grams.....	203	198	203
Volume, cubic centimeters.....	163	157	158
Specific gravity.....	1.24	1.26	1.29
Redipped.....	No.	No.	No.
Spiral wrapped.....	Yes.	Yes.	Yes.
Color.....	Dark corn.	Dark corn.	Dark corn.
Consistency:			
Granulation—			
Structure.....	Fibrous and granular.	Fibrous and granular.	Fibrous and granular.
Size.....	Fine.	Fine.	Fine.
Liquidness.....	Dry.	Dry.	Dry.
Compactness.....	Very soft.	Very soft.	Very soft.
Cohesiveness.....	Slightly cohesive.	Slightly cohesive.	Slightly cohesive.
Weight of cartridge shell per 100 grams of explosive ingredient, grams.....	8.0	8.0	8.0

CHEMICAL ANALYSIS.

[A. L. Hyde, analyst.]

Moisture.....	2.78	2.27	1.88
Nitroglycerin.....	32.77	32.91	32.67
Nitrotoluene.....	5.98	6.39	6.07
Sodium nitrate.....	31.03	31.45	32.18
Wood pulp and crude fiber.....	9.88	9.83	9.30
Starch.....	6.17	6.31	5.78
Sodium chloride.....	5.03	4.92	5.77
Sugar.....	5.00	4.61	4.93
Calcium carbonate.....	1.36	1.31	1.42
	100.00	100.00	100.00

^a 40 per cent strength low-freezing dynamites.

Because it was stated that the latest shipment of 40 per cent strength low-freezing dynamite received at Lock No. 1 was giving unsatisfactory results in that it seemingly did not develop the same energy as previous shipments, certain physical tests were made to

determine the comparative strength of samples of the shipment. The results of the tests indicated that the samples were uniform in strength, but, as all the tests were made with fresh explosives taken from the original containers, it was decided to make certain efficiency tests with the samples after they had been submerged in water for different periods of time and under varying conditions. It was also deemed advisable to make comparative tests with other classes of dynamite at the same time in order to determine the type of explosive most suitable for the submarine blasting in question.

The selection of an explosive for submarine work is of special importance because of the severe moisture and temperature conditions under which it must be used, also because of the great expense incurred in preparing every blast, a consideration that makes any failure of importance. It has also been generally recognized that when used for blasting under water explosives produce less useful work than when used for excavating on land. This decrease is due to the reduction of the temperature of the products of combustion and to the confining effect of the water on the material to be blasted, an effect that more than counteracts the beneficial effects of the water stemming.

Four different classes of explosives were used in the comparative-efficiency tests. They are commercially known as 40 per cent strength low-freezing dynamite, 40 per cent "straight" nitroglycerin dynamite, 40 per cent strength ammonia dynamite, and 40 per cent strength gelatin dynamite. The physical examination of each explosive gave the following results:

Results of physical examination of four classes of explosives.

Details observed.	40 per cent strength low-freezing dynamite.	40 per cent "straight" nitroglycerin dynamite.	40 per cent strength ammonia dynamite.	40 per cent strength gelatin dynamite.
Length of cartridge, inches.....	8 $\frac{1}{2}$	8.....	8.....	7 $\frac{3}{4}$
Diameter of cartridge, inches.....	1 $\frac{1}{4}$	1 $\frac{1}{4}$	1 $\frac{1}{4}$	1 $\frac{1}{4}$
Average weight, grams.....	254.....	238.....	241.....	295.....
Average volume, cubic centimeters.....	166.....	163.....	169.....	184.....
Specific gravity.....	1.53.....	1.46.....	1.43.....	1.60.....
Redipped.....	No.....	No.....	Yes.....	No.....
Spiral wrapped:.....	Yes.....	Yes.....	Yes.....	Yes.....
Color.....	Dark corn.....	Fawn.....	Light café au lait.....	Light café au lait.....
Consistency:				
Granulation—				
Structure.....	Fibrous and granular.....	Fibrous.....	Granular.....	Gelatinous.....
Size.....	Fine.....	Fine.....	Fine.....	Fine.....
Liquidness.....	Wet.....	Dry.....	Dry.....	Wet.....
Compactness.....	Soft.....	Soft.....	Soft.....	Soft.....
Cohesiveness.....	Slightly cohesive.....	Slightly cohesive.....	Slightly cohesive.....	Moderately cohesive.....
Weight of cartridge shell per 100 grams of explosive ingredient, grams.....	4.0.....	5.0.....	5.5.....	2.0.....

The results of the chemical analyses made disclosed the fact that these explosives were made under formulas somewhat similar to those of explosives of the same commercial rating generally offered

for sale in this country. The analyses of these classes of explosives are given in the following tabulation:

Results of analyses of four classes of explosives.

Constituent.	40 per cent strength low-freezing dynamite. ^a	40 per cent "straight" nitroglycerin dynamite. ^a	40 per cent strength ammonia dynamite. ^b	40 per cent strength gelatin dynamite. ^b
Moisture.....	1.13	0.97	0.88	1.47
Nitroglycerin.....	27.56	39.19	21.60	30.70
Nitrocellulose.....				.88
Ammonium nitrate.....			18.86	
Nitrotoluene.....	10.13			
Sodium nitrate.....	51.54	49.53	46.04	54.27
Wood pulp.....	8.52	9.77	5.45	8.58
Sulphur.....			4.85	3.08
Zinc oxide.....			.88	1.02
Calcium carbonate.....	1.12	.54	1.44	
	100.00	100.00	100.00	100.00

^a J. H. Hunter, analyst.

^b W. C. Cope, analyst.

TESTS OF EXPLOSIVES IN A FROZEN AND IN A THAWED CONDITION.

Tests were next made of explosives in a frozen and in a thawed condition.

The procedure in the first test was to submerge one cartridge of each class of explosive, in its original wrapper, under 1 foot of still water at a temperature of 1° C. (34° F.) for one hour. After taking the cartridges out of the water an attempt was made to fire each separately, unconfined, with a No. 6 electric detonator.

The cartridge of 40 per cent strength low-freezing dynamite was not frozen, but 2 inches of one end of the cartridge seemed to have absorbed an appreciable amount of water. When fired the detonation was seemingly complete.

The cartridge of 40 per cent "straight" nitroglycerin dynamite was found in a frozen condition. However, when fired complete detonation resulted. One-half inch of one end of this cartridge had absorbed water.

The cartridge of 40 per cent strength ammonia dynamite was found in a frozen condition but it detonated completely when fired. Two inches of one end of this cartridge had absorbed water.

The cartridge of 40 per cent strength gelatin dynamite was found in a frozen condition, but otherwise there was no change in its appearance. There had seemingly been no absorption of water. This cartridge failed to detonate when an attempt was made to fire it with a No. 6 detonator. All of the pieces of the cartridge that had been broken by the explosion of the detonator were recovered, and it was evident that not even a partial detonation of the cartridge had resulted.

Further tests were made with frozen cartridges under similar conditions, except that the cartridges were not submerged in water. They were taken from the magazine in a frozen condition and left for one hour at a temperature of -16°C . (3°F .).

Four cartridges each of 40 per cent "straight" nitroglycerin dynamite and of 40 per cent strength ammonia dynamite were fired separately, a complete detonation of each resulting.

Out of four trials, one failure to detonate occurred in tests of the 40 per cent strength low-freezing dynamite. With 40 per cent strength gelatin dynamite, failures to detonate occurred in each trial in each of four tests made.

Similar tests were then made by subjecting frozen cartridges of the four explosives to temperatures of 6°C . (43°F .) and of 8°C . (46°F .) for a few hours. Under these conditions the cartridges of 40 per cent strength gelatin dynamite were the only ones that failed to detonate. The results of the tests confirmed the previous results obtained with the gelatin dynamite. In no case was there even a partial detonation of the gelatin dynamite when attempts were made to fire it with a No. 6 electric detonator containing a 1-gram charge of fulminate composition.

Logical conclusions as a result of the tests of the explosives in a frozen and in a thawed condition are:

(1) That 40 per cent strength gelatin dynamite should never be used in blasting operations when the temperature is such as to cause the cartridges to freeze.

Attention is also called to the fact that some gelatin dynamites, after long storage in tropical countries, so lose their sensitiveness that they can not be detonated with the ordinary detonators generally used. This result is probably due to the fact that in the manufacture of gelatin dynamite the nitrocellulose used is not completely gelatinized, so that when the dynamite is stored in hot climates the process of gelatinization continues and, accordingly, the cartridges become harder and less sensitive.

(2) That, under the conditions that exist at Lock No. 1, the three other grades of dynamite are better adapted for use during the winter months.

However, it should be remembered that under actual mining conditions all of these grades have been known occasionally to detonate incompletely when used in a frozen condition, even when fired with No. 6 electric detonators. Therefore, it is preferable to use stronger electric detonators during the winter months.

Tests were also made to determine the disruptive effect developed by the four classes of dynamite in a frozen condition when fresh and when aged. The explosives were subjected to temperatures of 1°C . (34°F .) to -12°C . (10°F .), and tests were made by firing 100

grams of each explosive on lead blocks which were at room temperature, 18° C. (64° F.), the resulting compression being measured.

The tabulation following gives the results of small lead block tests made with each class of dynamite when used in a thawed, in a frozen, and in a frozen and aged condition. (See Pl. I.) The results of the tests herein reported, which were made in duplicate, checked within 5 per cent. No. 6 electric detonators, each containing a charge of 1 gram of fulminate composition, were used with the thawed explosives, but in order to increase the chances of detonation of the frozen explosives, No. 8 electric detonators, each containing a 2-gram charge of fulminate composition, were used. The compression resultant from the 40 per cent "straight" nitroglycerin dynamite, when thawed, is given a value of 100 per cent in the percentage strength column, and the results of tests with the other grades are computed on this basis in direct proportion.

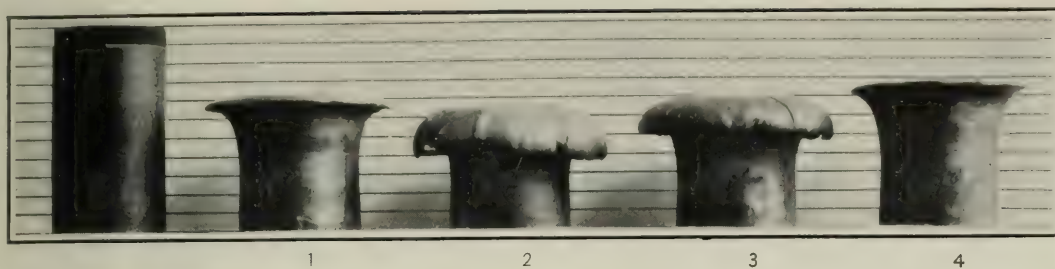
Results of small lead block tests with explosives in a thawed and in a frozen condition.

Physical condition of explosive.	Grade of electric detonator.	Class of explosive.							
		40 per cent strength low-freezing dynamite.		40 per cent "straight" nitroglycerin dynamite.		40 per cent strength ammonia dynamite.		40 per cent strength gelatin dynamite.	
		Average compression.	Disruptive effect.	Average compression.	Disruptive effect.	Average compression.	Disruptive effect.	Average compression.	Disruptive effect.
Thawed, in a fresh condition.	No. 6	<i>Mm.</i> 17.0	<i>Per ct.</i> 79.4	<i>Mm.</i> 21.4	<i>Per ct.</i> 100.0	<i>Mm.</i> 18.9	<i>Per ct.</i> 88.3	<i>Mm.</i> 15.6	<i>Per ct.</i> 72.9
Frozen, in a fresh condition..	No. 8	12.5	58.4	Block ruptured.		18.6	86.9	14.9	69.6
Frozen, 2½ per cent of water added and well mixed.....	No. 8	9.0	42.1	17.4	81.3	a 2.2	10.3	a .9	4.2
Frozen, 5 per cent of water added and well mixed.....	No. 8	a .2	0.9	a 1.5	7.0	a .9	4.2	a .8	3.7

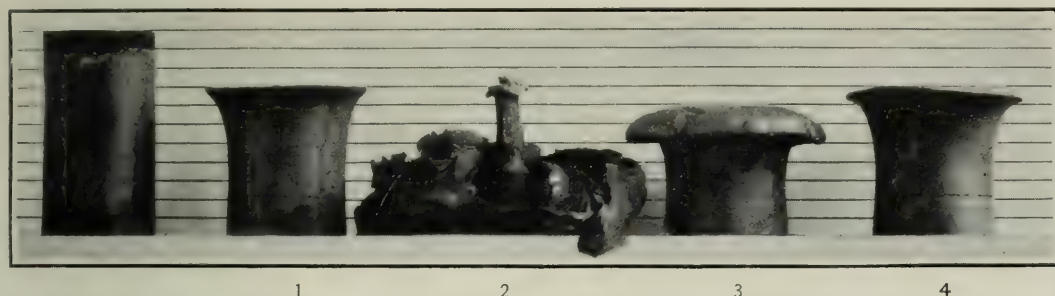
a Incomplete detonation.

In Plate I the effects of the several conditions are shown by *A*, *B*, *C*, and *D*; the effect of each explosive (low-freezing dynamite, "straight" nitroglycerin dynamite, ammonia dynamite, and gelatin dynamite) by blocks 1, 2, 3, and 4. An unused block, with steel cap in place, is shown at the left for comparison.

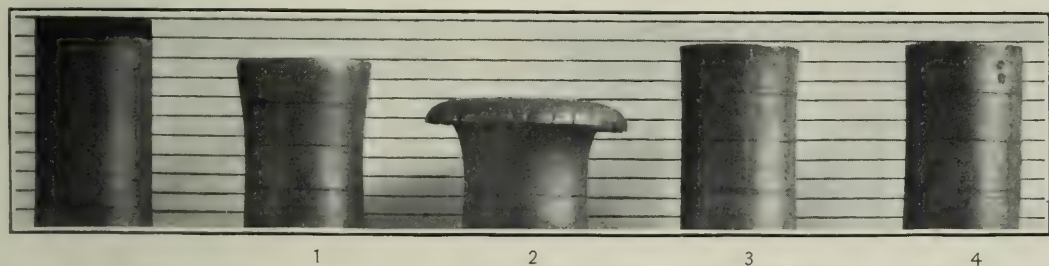
It is to be noted that 40 per cent strength low-freezing dynamite is the only class of explosive tested that showed a material loss in energy when fired in a frozen but fresh condition, when fired with No. 8 electric detonators (2-gram charge). It is also worthy of note that this is the first instance in the tests made that a detonation of frozen 40 per cent gelatin dynamite occurred. Attention is called, however, to the fact that comparatively small quantities of explosive in a fresh condition were used in the tests and also that



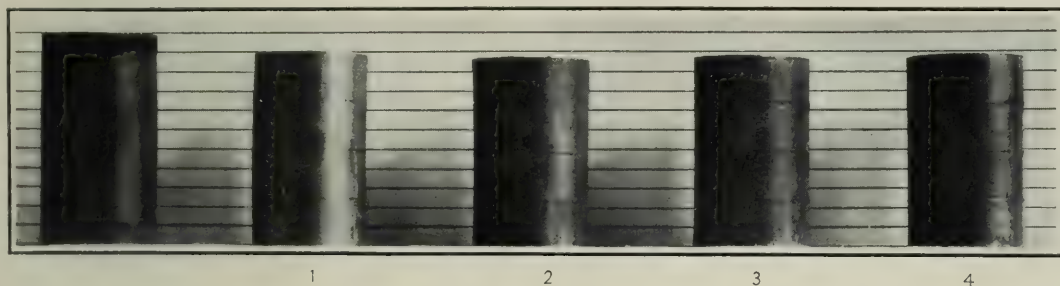
A. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES FRESHLY THAWED.



B. SMALL LEAD BLOCK TESTS OF FOUR FROZEN EXPLOSIVES IN A FRESH CONDITION.



C. SMALL LEAD BLOCK TESTS OF FOUR FROZEN EXPLOSIVES WITH $2\frac{1}{2}$ PER CENT OF WATER ADDED.



D. SMALL LEAD BLOCK TESTS OF FOUR FROZEN EXPLOSIVES WITH 5 PER CENT OF WATER ADDED.

they received the full effect of a powerful detonator. A greater loss in efficiency results with all classes of explosives after they have aged and taken up water if tested in a frozen condition with detonators of less strength. Furthermore, when large quantities of frozen explosives are used in actual mining operations it has been generally recognized that the results are erratic if the explosives are fired with No. 6 electric detonators, and are especially so when detonators of a lower grade are used.

The disruptive force of the 40 per cent "straight" nitroglycerin dynamite when frozen but in a fresh condition was not less than that of the same dynamite in a thawed condition; this result was probably due to the stronger detonator used.

The addition of water to the different classes of explosives represents the effect of aging from absorption of moisture through improper storage, but the facility with which these different classes of explosives absorb any definite percentage of moisture during storage varies widely. The gelatin dynamite absorbs little and that only slightly into its surface. On the other hand, the ammonia dynamite, when its wrapper is broken or distorted, allows its hygroscopic ingredients to absorb moisture with great facility. The above differences being kept in mind, the results of the small lead block tests of explosives to which $2\frac{1}{2}$ per cent of water has been added are properly interpreted as showing that those of the 40 per cent "straight" nitroglycerin dynamite are comparatively good, that those of the 40 per cent strength low-freezing dynamite are fair, that those of the 40 per cent strength ammonia dynamite are very poor, and that the results with the 40 per cent strength gelatin dynamite should not be interpreted as unfavorably as the test would seem to warrant. However, the results of tests with explosives to which 5 per cent of water has been added would probably indicate what may be expected from all classes of explosives stored under unfavorable conditions for a long period of time.

TESTS OF EXPLOSIVES IN A DRY AND IN A WET CONDITION.

A series of tests was undertaken to determine the energy of the four classes of explosives after they had been submerged in still water at a temperature of 17°C . (63°F .) for different periods of time.

It has been observed in practice that loss in efficiency results when explosives have been so submerged. The assumption has been that the resultant reduction of useful work is due to the fact that the nitroglycerin content of the explosives is to a certain extent replaced by water, and that certain of their ingredients, such as the nitrates, are soluble in water. The effect of water varies with the temperature, because the soluble salts of explosives are more readily dissolved in

warm than in cold water. The style of wrapper, particularly as regards the sealing of the ends of the cartridge to prevent the absorption of moisture by the explosive ingredients, is of especial importance. Little difference was found in the wrappers used on the cartridges under test, except that the cartridges of 40 per cent strength ammonia dynamite had been redipped during their manufacture and accordingly offered a greater protection to the explosive ingredients within.

One series of tests with the ballistic pendulum was made to determine the comparative strength of the explosives (with No. 6 electric detonators) expressed as a propulsive effect. Small lead block tests were made to determine the comparative strength expressed as a disruptive effect. The ballistic pendulum^a measures roughly the heaving force and the small lead blocks measure approximately the shattering force. The user of explosives, knowing which effect he desires to obtain, can use to advantage these results as a guide in selecting the explosive most suitable for his work.

In the tests, all of the cartridges were properly thawed before being submerged in water and, accordingly, were in a thawed condition when trials were made to determine their relative strength. The results of the tests are presented in the tabulations following. In the tabulations the results are referred to different series designated by letters, which are explained below.

SERIES A.

In the tests embraced in series A the explosives were tested as received.

SERIES B.

In the series B tests the explosives, in their original wrappers, were submerged for one hour under 1 foot of still water.

The average weight of the cartridges of 40 per cent strength low-freezing dynamite was 259 grams before soaking, and 270 grams after soaking, showing an increase in weight of 4.2 per cent. Each cartridge was soaked about 2 inches from the hand-crimped end of the cartridge shell.

The cartridges of 40 per cent "straight" nitroglycerin dynamite were affected in a similar way, except that the average increase in the weight of the cartridges was 2.4 per cent.

The cartridges of 40 per cent strength ammonia dynamite were soaked only one-fourth of an inch from the hand-crimped end of the cartridge shell, and the average increase in the weight of the cartridges was 1.1 per cent. It is worthy of note that this class of explosive, containing 19 per cent of ammonium nitrate, was little affected by the water test. This result was due to the protection afforded by the cartridge shells used, and shows the benefit of redipping the cartridges of explosives in melted paraffin.

The cartridges of 40 per cent strength gelatin dynamite showed little, if any, absorption of water. The average increase in the weight of the cartridges was 1.0 per cent. This increase was accounted for by the water that remained inside the cartridge and on the surface of the plastic ingredients.

^a See pp. 45-46.

SERIES C.

In the series C tests the explosives were submerged for one hour under 1 foot of still water but the cartridges were previously slit three times from end to end. This was done in order to represent unusually rough handling of the cartridges, and also to determine the effect of water on the cartridges of explosives when rammed into the drill holes.

The cartridges of 40 per cent strength low-freezing dynamite, of 40 per cent "straight" nitroglycerin dynamite, and of 40 per cent strength ammonia dynamite showed, respectively, an average loss in weight of 7.0, 8.7, and 1.1 per cent. All cartridges seemed to be saturated thoroughly and uniformly.

The cartridges of 40 per cent strength gelatin dynamite showed an average loss in weight of only 0.3 of 1 per cent. There was no visible change in the appearance of the explosive ingredients.

The loss in weight of the other classes of explosives is only partly indicated by the figures given, because there was a certain absorption of water which tends to increase their weights. It was observed during the tests that the cartridges at first gained weight by taking up water and then lost weight by the dissolving of the soluble ingredients.

SERIES D.

In the tests embraced in series D the cartridges, in their original wrappers, were submerged for eight and one-half hours under 1 foot of still water.

The cartridges of 40 per cent strength low-freezing dynamite, of 40 per cent "straight" nitroglycerin dynamite, of 40 per cent strength ammonia dynamite, and 40 per cent strength gelatin dynamite showed an average increase in weight of 0.0, 2.1, 8.1, and 4.2 per cent, respectively. All cartridges, except those of 40 per cent strength gelatin dynamite, were thoroughly and evenly saturated, and after they had been allowed to stand the usual time for draining at room temperature it was noted that the lower ends of the outside of the cartridge shells for a distance of 2 inches were covered with crystallized nitrates.

The cartridges of 40 per cent strength gelatin dynamite showed no change in the appearance of the cartridge shells or of the explosive ingredients.

SERIES E.

In the series E tests the cartridges, in their original wrappers, were submerged for eight and one-half hours under 1 foot of still water but the cartridges were previously slit three times from end to end.

The cartridges of 40 per cent strength low-freezing dynamite, 40 per cent "straight" nitroglycerin dynamite, 40 per cent strength ammonia dynamite, and 40 per cent strength gelatin dynamite showed an average loss in weight of 13.8, 16.0, 14.4, and 0.0 per cent, respectively. All of the cartridges, except those of 40 per cent strength gelatin dynamite, were completely saturated so that in taking them out of the water extreme care was required in order to retain the explosive ingredients in the cartridge shells. As in all previous tests, there was no visible change in the appearance of the cartridges of 40 per cent strength gelatin dynamite. In none of the tests was any liquid nitroglycerin found in any of the pails used, and only in the series E tests was any appreciable quantity of sediment found in the bottom of the pails.

BALLISTIC-PENDULUM TESTS.

The results of the ballistic-pendulum tests are tabulated below:

Results of ballistic-pendulum tests to determine the comparative propulsive effect of four explosives.

AMOUNTS OF EXPLOSIVES EQUIVALENT TO 227 GRAMS ($\frac{1}{2}$ POUND) OF STANDARD TESTING-STATION 40 PER CENT "STRAIGHT" NITROGLYCERIN DYNAMITE.

Series—	40 per cent strength low-freezing dynamite.	40 per cent "straight" nitroglycerin dynamite.	40 per cent strength ammonia dynamite.	40 per cent strength gelatin dynamite.
	Grams.	Grams.	Grams.	Grams.
A.....	229	234	241	283
B.....	233	240	247	288
C.....	239	235	258	282
D.....	235	241	279	281
E.....	^a 1,009	^a 857	^a 848	279

COMPARATIVE STRENGTHS IN PERCENTAGES.^b

A.....	102	100	97	83
B.....	100	98	95	81
C.....	98	100	91	83
D.....	100	97	84	83
E.....	^a 23	^a 27	^a 28	84

^a One shot of each failed to explode.
^b 40 per cent "straight" nitroglycerin dynamite in its ordinary condition is given a value of 100 per cent, the results of the tests being computed in direct proportion on this basis.

The results of the tests of the explosives in the form received (series A) show that the propulsive effect developed by the 40 per cent strength low-freezing, the 40 per cent "straight" nitroglycerin, and the 40 per cent strength ammonia dynamites were practically the same. It is evident, however, that the 40 per cent strength gelatin dynamite is not as efficient and will not develop the same heaving and pushing force as the other types of explosives.

In the series B tests (cartridges soaked in their original wrappers for one hour in still water) it is to be noted that there was no material loss in the propulsive effect of any of the explosives tested.

In the tests embraced in series C the cartridges that had been previously slit and then soaked for one hour in still water did not show any reduction in the propulsive effect from that obtained in the series B tests.

In the series D tests, embracing cartridges soaked in their original wrappers for eight and one-half hours in still water, the 40 per cent strength ammonia dynamite showed a loss in propulsive effect of 13 per cent. With the other explosive there was no perceptible reduction; the variations in results obtained are within the limits of error of the apparatus.

The greatest reduction of propulsive effect is shown in the results of the series E tests (cartridges slit from end to end and then submerged for eight and one-half hours under 1 foot of still water). The

40 per cent strength low-freezing dynamite, the 40 per cent "straight" nitroglycerin dynamite, and the 40 per cent strength ammonia dynamite showed losses in propulsive effect of 77, 73, and 72 per cent, respectively. The 40 per cent strength gelatin dynamite, as in all previous soaking tests, showed no loss in propulsive effect.

SMALL LEAD BLOCK TESTS.

The results of the tests with small lead blocks are given in the following tabulation:

Results of small lead-block tests to determine the comparative disruptive effect of explosives.

COMPRESSION OF LEAD BLOCKS.

Series—	40 per cent strength low-freezing dynamite.	40 per cent "straight" nitroglycerin dynamite.	40 per cent strength ammonia dynamite.	40 per cent strength gelatin dynamite.
	<i>mm.</i>	<i>mm.</i>	<i>mm.</i>	<i>mm.</i>
A.....	17.0	21.4	18.9	15.6
B.....	13.0	18.0	13.6	13.5
C.....	11.9	11.4	10.5	14.2
D.....	13.5	11.4	10.9	13.5
E.....	.0	.0	.0	12.6

COMPARATIVE STRENGTHS IN PERCENTAGES.^a

A.....	79	100	88	73
B.....	61	84	64	63
C.....	56	53	49	66
D.....	63	53	51	63
E.....	0	0	0	59

^a 40 per cent "straight" nitroglycerin dynamite in its ordinary condition is given a value of 100 per cent, the results of the tests being computed in direct proportion on this basis.

The appearance of the blocks after the tests is shown in Plate II, in which *A*, *B*, *C*, *D*, and *E* represent the corresponding series in the table of results, and 1, 2, 3, and 4 the blocks deformed by the action of low-freezing, "straight" nitroglycerin, ammonia, and gelatin dynamite, respectively.

It has often been observed that gelatin dynamite used unconfined rather than confined suffers a greater loss of efficiency than do the other three classes of "high" explosives. Consequently it is not surprising that the compression of the small lead blocks was less with this explosive than with the others tested. The observation mentioned is illustrated by the results of the tests, as follows:

The compression of the small lead block by the 40 per cent "straight" nitroglycerin dynamite fired in the usual way was 21.4 mm., but when the dynamite was confined in a can of water 6 inches high and 3½ inches in diameter the compression was 22.6 mm., a difference of 1.2 mm. On the other hand, the compression by 40 per cent strength gelatin dynamite, fired in the usual way, was 15.6 mm but

when the dynamite was confined in a can of water 6 inches high and $3\frac{1}{8}$ inches in diameter the compression was 20.9 mm., a difference of 5.3 mm. The above results, however, must be interpreted with regard to the fact that the mechanical equivalent of the compression of lead increases per unit compression with an increase in the compression.

In the tests made with explosives as received (series A) the greatest disruptive effect was developed with 40 per cent "straight" nitroglycerin dynamite; accordingly, this class of explosive exerts the greatest shattering force.

When the cartridges in their original wrappers were soaked for one hour (series B) the 40 per cent "straight" nitroglycerin dynamite again showed the highest efficiency, but when the cartridges were slit and soaked for one hour this superiority did not exist.

It is evident from the results of the tests embraced in series C that 40 per cent strength gelatin dynamite, as compared with the other explosives tested, develops the greatest disruptive effect when the cartridges are slit and soaked for one hour, or when cartridges in their original wrappers are soaked for $8\frac{1}{2}$ hours, as in the series D tests.

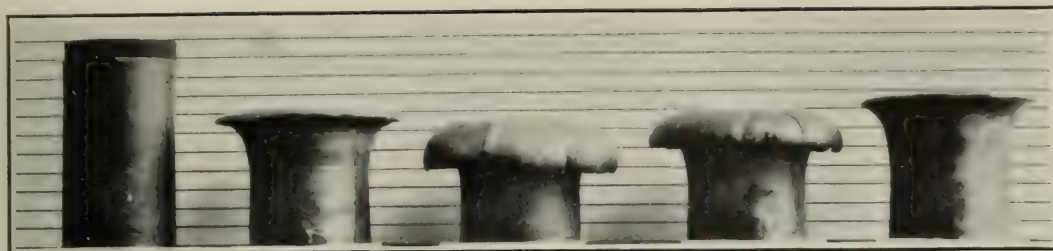
When the cartridges were slit and soaked $8\frac{1}{2}$ hours (series E) the 40 per cent strength gelatin dynamite showed a loss in disruptive effect of 14 per cent. Under the same conditions the other classes of dynamites failed to detonate with No. 6 detonators, or at least sufficient energy was not developed to deform the lead blocks in any of the tests made.

PRACTICAL CONCLUSIONS.

The procedure followed in connection with the work of blasting rock in the bottom of the Monongahela River at Lock No. 1 is in accordance with good mining practice. All explosives are carefully loaded in drill holes. They are not simply placed on the material to be blasted, a practice that, although sometimes followed in work of this kind, can not be considered economical.

In reference to the electric detonators used, it would seem that No. 6 electric detonators are satisfactory for the work, except during the winter months when the temperature of the water is low enough to cause the explosive charge to freeze. The factor of safety would be greater if No. 7 or No. 8 electric detonators were used.

In view of the fact that out of 286 shots fired only one detonator failed to explode owing to the absorption of water, the use of the more expensive waterproof electric detonators is not warranted. However, attention is called to the fact that electric detonators similar to those now being used for wet work on the Isthmus of Panama can be purchased at the same cost as ordinary electric detonators. Such detonators contain a viscous compound between the sulphur plug



1

2

3

4

A. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES AS RECEIVED.



1

2

3

4

B. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES SOAKED IN WATER FOR ONE HOUR IN THEIR ORIGINAL WRAPPERS.



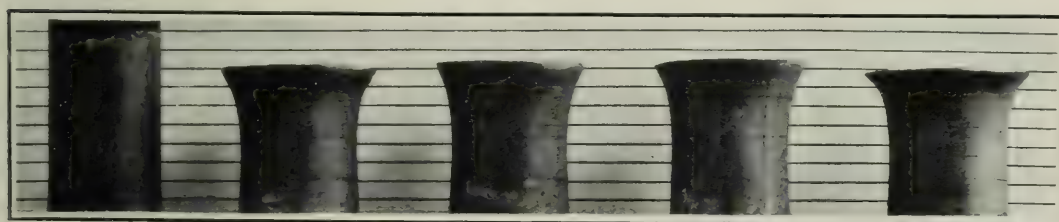
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C. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES SLITTED AND SOAKED IN WATER FOR ONE HOUR.



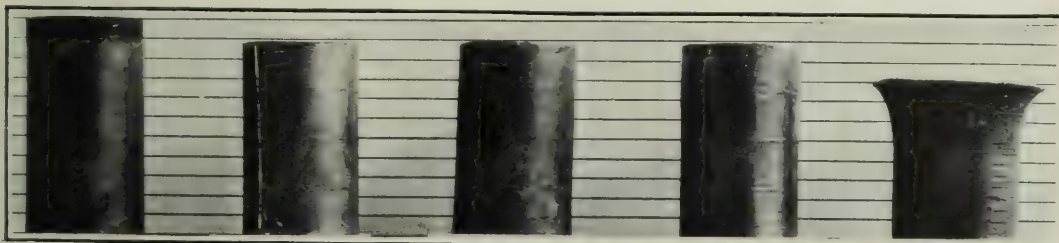
1

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3

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D. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES AFTER SOAKING IN WATER FOR EIGHT AND ONE-HALF HOURS IN THEIR ORIGINAL WRAPPERS.



1

2

3

4

E. SMALL LEAD BLOCK TESTS OF FOUR EXPLOSIVES SLITTED AND SOAKED IN WATER FOR EIGHT AND ONE-HALF HOURS.

and the sulphur filling of the detonator. An electric detonator so manufactured withstands submersion in water for several hours.

In reference to the operation of the No. 3 firing machine, the recommendation is made that the ratchet bar be pushed down quickly and forcibly in order to obtain the maximum speed of the revolving armature. This manner of operation is necessary, because the cross-sectional area of the platinum bridges of electric detonators is not uniform, and as a result some detonators will fail if sufficient current is not produced to heat all the bridges to the proper temperature.

From the results of tests reported herein it is evident that 40 per cent "straight" nitroglycerin dynamite is the most suitable class of explosive for this submarine work.

If the work required longer intervals in the preparation of the shots, or if there were a material change in the character of the rock to be blasted, requiring explosives of different characteristics, the other classes of explosives might be used to advantage, subject to the conditions set forth in this publication.

TESTS OF EFFECT OF SUPERINCUMBENT MATERIAL.

As practically all primary blasting is done in material that is in some measure confined, it is reasonable to assume that this confining material will always offer resistance to the force of explosives and that the resistance will vary with the kind of material and the degree of confinement.

From what has been said before, it is obvious that the useful work that is obtained from explosives depends upon the class and grade of explosive, the quantity used, its physical condition, the method of application and the material blasted, but in submarine blasting there is another factor that is more liable to be overlooked than any of these although it is of great importance, namely, the effect of the superincumbent material.

In order to illustrate the importance of this factor, tests on small lead blocks and on a high grade of limestone were made, all conditions being the same except the character of the superincumbent material. In one case the quantity of explosive used was also varied.

The equipment used in the small lead block tests ^a is shown in figure 6. In addition to the regular small lead block equipment, cylinders containing water were used as shown in the figure. In one case only the charge of explosive was immersed in a cylinder of water, which in turn rested on the steel plate on top of the lead block. In the other case the explosive, the steel plate, and the lead block were all immersed in the water. With the explosive only immersed, the compression due to explosion was 17.8 mm. With the explosive,

^a See also pp. 35-36.

the steel plate, and the block all immersed. the compression was 13.0 mm. In each of these tests 100 grams of 40 per cent strength gelatin dynamite was used and the lesser compression was a result of the confining effect of the water surrounding the small lead block.

“Adobe shots” were then made on two high-grade limestone blocks cut from the same large block and weighing 215 and 203 pounds (see *a* and *c*, Pl. III, *A*). Each block was approximately a cube, measuring 12½ by 12½ by 13 inches. The heavier block was selected for tests in the air. It was laid on two 6 by 6 inch timbers, and on

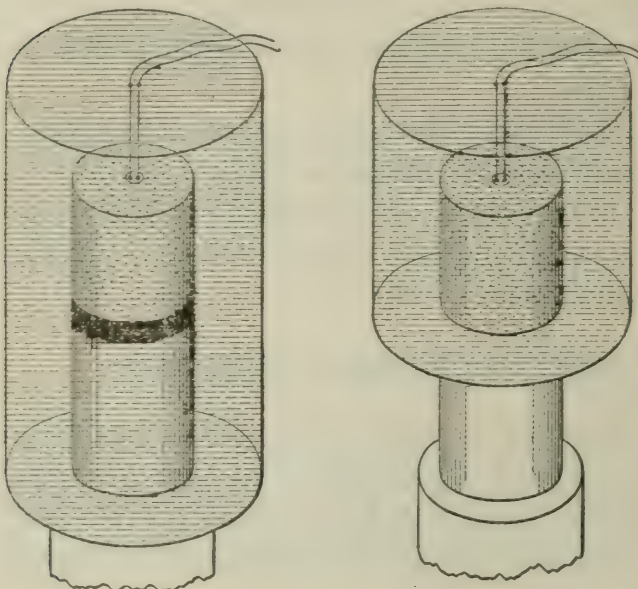


FIGURE 6.—Equipment used in tests to show the effect of surrounding medium on compression of small lead blocks by an explosive.

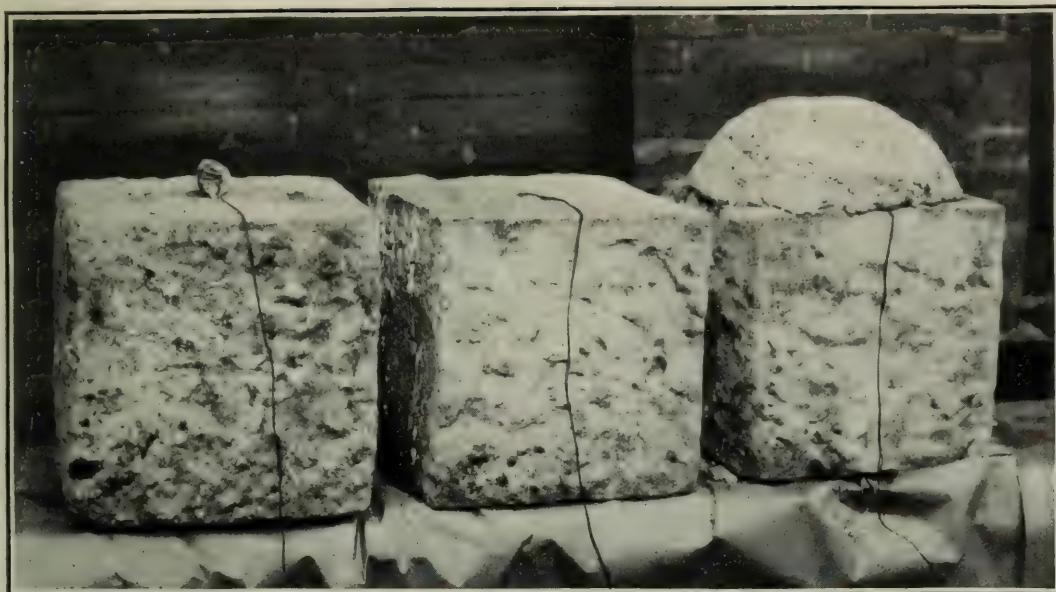
the center of the top side a 50-gram 1¼-inch cartridge of the 40 per cent strength low-freezing dynamite was placed. A No. 6 electric detonator was inserted in the cartridge and laid parallel to the vertical bedding planes of the block. The charge was then covered with a 35-pound mud cap consisting of 30 pounds of dry fire clay mixed with 5 pounds of water (see *c*, Pl. III, *A*) and fired. The block was not shattered on top, but pieces were split off around the sides (see *b*, Pl.

III, *B*). The other block was then immersed in a barrel of water having a temperature of 70° F. The water was 32 inches deep, there being 13¼ inches of water above the block. The charge was the same as in the previous trial except that no mud cap was used, and the charge was coated with paraffin in order to protect it from absorbing water. On firing no apparent damage was done to the block and no cracks were visible. This trial was then repeated on the same block immersed in water with a charge of 100 grams (see *a*, Pl. III, *B*). This greater charge did not break up the block as much as did the 50-gram charge when the block was in air only. The following tabulation shows comparative results:

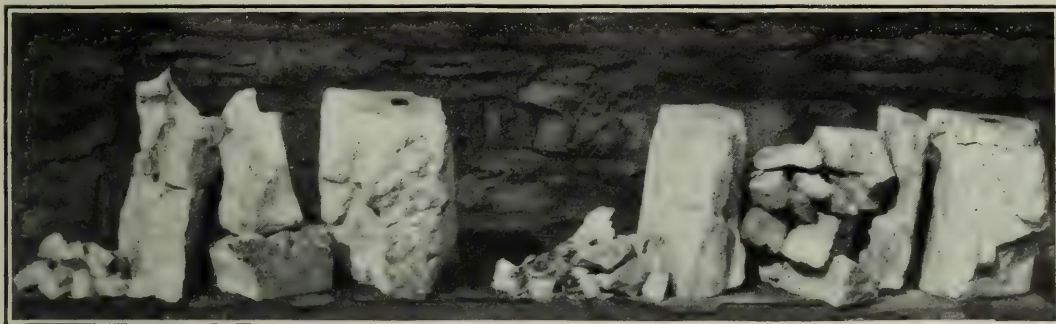
Comparative results of adobe shots on limestone blocks.

Condition of block.	Quantity of explosive used.	Weight of block.	Weight of largest piece.	Number of pieces over 3 inches in diameter.	Average weight of these pieces.	Total weight of small pieces.
	<i>Grams.</i>	<i>Pounds.</i>	<i>Pounds.</i>		<i>Pounds.</i>	<i>Pounds.</i>
In air.....	50	215	82	13	15.5	11
In water.....	a 100	203	104	8	24.6	5

a After firing a 50-gram charge.

*a**b**c*

A. LIMESTONE BLOCKS BEFORE TESTS: *a*, BLOCK AND CHARGE BEFORE PUTTING ON MUD CAP FOR ADOBE TEST; *b*, BLOCK DRILLED AND CHARGED FOR BLOCK-HOLE TEST; *c*, BLOCK AND CHARGE AFTER PUTTING ON MUD CAP FOR ADOBE TEST.

*a**b*

B. RESULTS OF ADOBE TESTS: *a*, WITH BLOCK IMMERSSED IN WATER, CHARGE, 100 GRAMS OF 40 PER CENT STRENGTH LOW-FREEZING DYNAMITE; *b*, WITH BLOCK IN AIR, CHARGE, 50 GRAMS OF SAME EXPLOSIVE.

*a**b*

C. RESULTS OF BLOCK-HOLE TESTS: *a*, WITH BLOCK IMMERSSED IN WATER, CHARGE, 5 GRAMS OF 40 PER CENT STRENGTH LOW-FREEZING DYNAMITE; *b*, WITH BLOCK IN AIR, CHARGE, 5 GRAMS OF SAME EXPLOSIVE.

Other similar tests confirmed in every particular these tests, and again the confining effect of the surrounding material was shown. The above experimental proof is presented as a confirmation of practical experience that submarine blasting requires larger charges to disrupt a given amount of material than open work on similar materials.

Block-hole tests were made on two similar high-grade limestone blocks cut from the same large block and weighing 198 and 205 pounds. A hole 1 inch in diameter and 6 inches deep was drilled from the center of one side to the center of the block. (See *b*, Pl. III, *A*.) Each was charged with 5 grams of the 40 per cent strength low-freezing dynamite. A No. 6 electric detonator was used. The bore hole was filled with water in each case. The 198-pound block was fired in air (see *b*, Pl. III, *C*) and the 205-pound block was suspended in a barrel of water in the same manner as in the previous tests. Both blocks were broken (see *a*, Pl. III, *C*). The following tabulation shows the confining effect of the surrounding water:

Comparative results of block-hole tests with limestone blocks.

Condition of block.	Quantity of explosive used.	Weight of block.	Weight of largest piece.	Number of pieces over 2 inches in diameter.	Average weight of pieces over 2 inches in diameter.	Total weight of small pieces.
	<i>Grams.</i>	<i>Pounds.</i>	<i>Pounds.</i>		<i>Pounds.</i>	<i>Pounds.</i>
In air.....	5	198	52	15	12.7	7
In water.....	5	205	59	11	18.2	5

Incidentally the tests with the high-grade limestone blocks show the superiority of the block-hole method of shooting as compared with adobe shooting, even though the mud cap in the adobe shooting be very large.

**DETERMINATION OF THE RELATIVE ENERGY AND
EFFICIENCY OF EXPLOSIVES.^a**

It is evident that in hard-rock blasting operations in which a shattering effect is desired, the explosive reaction should be quick and explosives should be selected having a high rate of detonation. Likewise, for work in soft and friable ground an explosive should be selected that develops gases at a slow rate, in order that the pressure exerted will be more prolonged. In medium hard rock one might expect that an explosive having an intermediate rate would be most

^a For detailed descriptions of methods and apparatus used at the Pittsburgh experiment station for testing explosives, see Bull. 15, Bureau of Mines, Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe, 1912. 194 pp., 7 pls.

suitable, but such is not always the case. The lack of uniformity in rocks and the fact that a perfectly homogeneous mass or bed rarely exists are important considerations in blasting. In the Middle West there are fairly uniform limestone beds 12 to 14 feet thick in which quarry operations are being conducted. In one of these quarries visited by the writers, stone was being produced in one part of the quarry at a cost of 6 cents per ton for the explosives used. An explosive having a low rate of detonation gave satisfactory results there. In another part of the same quarry a different type of explosive having a much higher rate of detonation was found necessary in order to produce stone at the same cost, because local irregularities, such as clay "slips" and bedding cracks were more pronounced in that part of the quarry. Practical experience had shown that an explosive that develops its gases at a slow rate loses much of its energy through the escape of the evolved gases along the clay "slips," its efficiency being thus reduced.

After a suitable class of explosive has been selected, it is necessary to determine the grade or strength of the explosive that is best adapted to the proposed work and that produces most economical results. It is well known that the potential energy of an explosive can be computed by measuring in a calorimeter the heat evolved on explosion. The potential energy thus obtained represents the maximum work that an explosive can theoretically accomplish. But as the useful work resulting from the use of explosives is a small percentage of the theoretical maximum, and varies considerably with the different classes of explosives, knowledge of the potential energy of explosives is of little value to the engineer in selecting a suitable explosive. For example, blasting gelatin, which is considered, on account of its high potential energy, the most powerful blasting agent known and hence the ideal explosive, has seldom given satisfactory or economical results in practice in this country. This is probably because the physical character of blasting gelatin is such that rapid detonation is not obtained with the means or devices ordinarily used in this country for detonating explosives.

It has been impossible to devise a single piece of apparatus for measuring both the disruptive and the propulsive effects produced by explosives. The apparatus used at the Pittsburgh testing station for determining these factors, which approximates the determination of the relative strength of explosives, is briefly described below, a tabulation of the results of tests made with different explosives being presented.

MEASUREMENT OF POTENTIAL ENERGY.

The apparatus used at the Pittsburgh experiment station for measuring the potential energy of explosives is the calorimeter.

CALORIMETER.

The construction of the explosives calorimeter is similar to that of the bomb calorimeters used for determining the heating value of fuels. The reacting bodies are exploded in a bomb enveloped by a mass of water of known weight, and the increase in temperature of the water is measured with great precision. The bomb is made large and strong so that it may withstand the tremendous pressures resulting from the explosion. It is air-tight and practically all of the air it contains is pumped out by means of a rotary pump, before the charge is placed within it.

The bomb has a capacity of 30 liters and weighs 158 pounds. It is provided with a cover through which the charge may be placed, a valve through which the air may be pumped, and an insulated plug for carrying the electric current to the detonator placed in the charge. The charge used is 100 grams. No oxidizing material other than that supplied by the explosive itself is used. The water in which the bomb is submerged weighs 182 pounds. The rise in temperature of this water after the explosion of a charge is measured by a thermometer reading to thousandths of a degree Centigrade. Each result herein reported is the average of two tests agreeing within 5 per cent.

MEASUREMENT OF DISRUPTIVE EFFECT.

The devices used to measure approximately the disruptive effect of explosives, which bears a close relation to the percussive or shattering force, are the rate of detonation apparatus, Trauzl lead blocks, and small lead blocks.

METTEGANG RECORDER.

The rate of detonation apparatus comprises a Mettegang recorder and a covered pit in which the charge made up into a cartridge file is placed previous to the test.

The Mettegang recorder consists of a soot-covered bronze drum, pointed platinum terminals, tooth gear, and measuring adjustment, electric motor, vibration tachometer, and induction coils having primaries without iron cores. The drum is 500 millimeters in circumference and may be driven at any speed up to 105 revolutions per second. One edge of the drum is provided with 500 teeth, the same number as there are millimeters in the circumference. An endless screw engages these teeth and a pointer on this screw moves on a dial. Four platinum terminals are held by a nonconducting arm which may be moved so that the points are any desired distance from the drum. Each point is in series with a secondary coil, the other terminal of which is grounded to the drum through the base of the machine. Each primary coil is in series with ten 16-candlepower

lamps and a copper wire running through one end of the cartridge file. The current used in the primary circuit has a potential of 220 volts. The vibration tachometer is connected to an auxiliary shaft, which engages the main shaft by gears, thus preventing any irregularity in speed due to slipping. The points of the drum are focussed on the cross hairs of a filar eyepiece which, with the endless screw, provides an exact means of measuring the distance between the two points.

The pit in which the cartridge file is suspended is 16 feet in diameter and 11 feet deep, and is closed at the top by means of a heavy reinforced concrete cover. A manhole in this cover provides entrance to the interior.

Each rate-of-detonation result herein reported is the average of two trials agreeing within 5 per cent. The determination was made on a cartridge file of explosive $1\frac{1}{4}$ inches in diameter and 1 meter in length, inclosed in a galvanized sheet-iron tube 42 inches long and $1\frac{1}{2}$ inches in internal diameter. Copper wires leading from the Mettegang recorder were passed through the cartridge file 1 meter apart, the cartridge file was exploded, and from the time interval between the breaking of the wires, as shown by the recorder, was computed the rate of detonation.

The rate of burning of black blasting powder was determined by placing it in a hydraulic pipe having an inside diameter of $1\frac{1}{2}$ inches. Each end of the pipe was filled with plaster of paris, the plaster extending for 4 inches at one end and for 1 inch at the other end. The charge was fired by means of an electric igniter. The time interval was determined by the Mettegang recorder.

DETONATING FUSE (CORDEAU DETONANT).

A unique method for determining the rate of detonation of explosives by means of detonating fuse (cordeau detonant), known as the Dautriche method,^a is as follows:

A cartridge of explosive or an explosive file is suspended freely in the air, and at two points within the cartridge or file at a known distance apart are placed two detonators into each of which is previously crimped one end of a continuous detonating fuse, usually about 1 yard long. This fuse is bent so as to lie on a lead plate $\frac{1}{2}$ by 3 by 15 inches in such a way that its middle point is directly over a previously marked position on the plate. The detonation of the cartridge of explosive detonates the detonators, and these in turn detonate an end of the detonating fuse. The point on the lead plate at which the detonations in the fuse meet is easily determined. The fuse has a known rate of detonation and from this, and the distance between the mark showing the middle point of the

^a Comey, A. M., Study of the velocity of detonation: 7th Inter. Cong. App. Chem., Sec. IIIB, p. 28.

detonating fuse and the point on the lead plate at which the detonations meet, may easily be computed the rate of detonation of the explosive. The detonating fuse, known as "cordeau detonant," is made in diameters of 4 mm. and 6 mm., costs about 10 to 15 cents per yard, and may now be procured in this country. A few tests have been made with it at the testing station of the Bureau of Mines. The results obtained were fairly uniform and compared favorably with the results obtained with a Mettegang recorder as heretofore described.

TRAUZI LEAD BLOCKS.

The Trauzl lead-block test was conducted in the manner approved by the Fifth International Congress of Applied Chemistry. A cylindrical block of desilverized lead 200 millimeters in diameter and 200 millimeters in height, with an axial bore hole, 25 millimeters in diameter and 125 millimeters deep, was used. A charge of 10 grams of explosive was tamped with dry sand to the mouth of the bore hole and fired. No effort was made to confine the explosive further by means of plates and a yoke. The expansion of the bore hole was determined in cubic centimeters by measuring the volume of the bore hole with water before and after firing. Each result herein reported is the average of two tests agreeing within 5 per cent.

SMALL LEAD BLOCKS.

The small lead blocks are cylindrical in shape, $2\frac{1}{2}$ inches long, and $1\frac{1}{2}$ inches in diameter. Each block is inclosed in a piece of paper in such a way that a shell in which to place the charge is formed above the block. An annealed steel disk $1\frac{1}{2}$ inches in diameter and one-fourth inch high is placed on top of the block. The block is placed on a firm horizontal base previous to firing the charge. A 50-gram charge of normal specific gravity is used in these tests. The electric detonator is centrally placed in the top of the charge. Compression of the lead block is determined in millimeters from its height before and after the explosion of the charge. Each result herein reported is the average of two tests agreeing within 5 per cent. This test is not suitable for use with black blasting powder as it provides little confinement for the charge.

The results of tests made to determine the disruptive effect of the various classes of explosives, as measured by the rate-of-detonation apparatus, Trauzl lead blocks, and small lead blocks, is given in the accompanying tabulation. The strength of 40 per cent nitroglycerin dynamite is taken as 100 per cent and the values for other grades are computed on this basis.

Results of tests of the disruptive effect of explosives.

Class and grade of explosive.	Diameter of cartridge (inches).	Number of electric detonator used.	Specific gravity of cartridge.	Rate of detonation.			Trauzl blocks.		Small lead blocks.	
				Meters per second.	Feet per second.	Percentage strength.	Expansion (c. c.).	Percentage strength.	Compression (mm.).	Percentage strength.
30 per cent "straight" nitroglycerin dynamite.....	1 1/4	6	1.31	4,548	14,920	95.3	196	73.4	17.3	83.6
40 per cent "straight" nitroglycerin dynamite.....	1 1/4	6	1.24	4,772	15,650	100.0	267	100.0	20.7	100.0
50 per cent "straight" nitroglycerin dynamite.....	1 1/4	6	1.38	5,748	18,850	120.5	281	105.2	21.1	101.9
60 per cent "straight" nitroglycerin dynamite.....	1 1/4	6	1.37	6,246	20,490	130.9	321	120.2	22.4	108.2
60 per cent strength low-freezing dynamite.....	1 1/4	6	1.14	5,072	16,640	106.3	246	92.1	17.0	82.1
40 per cent strength ammonia dynamite.....	1 1/4	6	1.57	3,157	10,350	66.2	202	75.7	12.8	61.8
40 per cent strength gelatin dynamite.....	1 1/4	6	1.65	4,943	16,210	103.6	195	73.0	12.1	58.5
5 per cent granulated nitroglycerin powder.....	1 1/2	a 6	1.21	1,018	3,340	21.3	58	21.7	4.5	21.7
Black blasting powder.....	1 1/2	(b)	1.25	469	1,540	9.8	28	10.5	0.0	0.0

a A primer of 40 per cent "straight" nitroglycerin dynamite, representing 10 per cent by weight of the charge, was used in all the tests with this powder except those with the Trauzl lead blocks, and the energy produced by the primer is not included, except in the small lead-block tests.

b Black-powder igniter used.

MEASUREMENT OF PROPULSIVE EFFECT.

The apparatus used to measure approximately the propulsive effect of explosives, which corresponds closely to their heaving or pushing force, are the Bichel pressure gages and the ballistic pendulum.

BICHEL PRESSURE GAGES.

The pressure exerted by explosives is determined by means of the Bichel pressure gages. The test determines the theoretical maximum pressure developed by an explosive in its own volume after the elimination of the cooling influence of the surface of a gage.

The gages comprise two stout steel cylinders that may be made air-tight, each having an insulated plug for providing a means of igniting the charge, an air pump and proper connections for exhausting the air in either cylinder to an absolute pressure of 10 mm. of mercury, a valve by means of which this air pump can be isolated from the cylinder, and an indicator mechanism, the drum of which may be driven by a motor at a known speed. The cover of each cylinder is a heavy piece of steel held in place by 12 heavy stud bolts and an iron yoke. The piston of the indicator has a diameter of 0.3937 cm. and is resisted by one of several spiral springs of different strength. The particular one used is determined by the character of the explosive tested. The graphic record of the pressure developed within the cylinder is recorded on a paper placed on the circumference of the indicator drum. One of the cylinders has a capacity of 15 liters. The other cylinder is similar to the 15-liter cylinder in all

particulars except that its capacity is 20 liters. In it, however, one or three steel cylinders are placed to reduce the capacity to 15 liters. The 15-liter cylinder has a cooling surface of 3,914 sq. cm. The 20-liter cylinder has a cooling surface, when the one large steel cylinder is in place, of 6,555 sq. cm., or, when the three smaller steel cylinders are in place, of 7,624 sq. cm. The charge of explosive used is 200 grams plus the weight of the paper wrapper. The weight of the wrapper bears the same relation to the weight of the explosive used in the test that it bears to the weight of the explosive in the original cartridge. Each result is the computed pressure in own volume as determined by the formula $M = \frac{VPS}{W}$, in which V represents the volume of the gage, which is always 15,000 cubic centimeters; S, specific gravity of the cartridge, and W, the weight in grams of the charge used in the test. It is important to observe the direct effect that the specific gravity has on the computed pressure in own volume, because any increase in the specific gravity gives a corresponding increase in the computed pressure in own volume. This relation is illustrated in the case of the 30 per cent "straight" nitroglycerin dynamite in the table on page 47.

P is determined by means of the formula $P = 1.911A + 0.5B - 1.411C$, in which P represents the pressure with elimination of cooling surface and probable error; A, pressure developed with cooling surface of 3,914 sq. cm.; B the pressure developed with cooling surface of 6,555 sq. cm.; and C the pressure developed with cooling surface of 7,624 sq. cm. This formula expresses the geometrical relation obtained by plating the average pressure developed in two tests, agreeing within 5 per cent for each cooling surface, against the area of the cooling surface, the line drawn through the three points being extended to the ordinate of zero cooling surface. By plating the pressures against the cooling surfaces the effects of the cooling surfaces are eliminated.

BALLISTIC PENDULUM.

The ballistic pendulum is used to measure the deflective force of explosives. The apparatus consists of a 12.2-inch mortar suspended as a pendulum from a beam having knife edges, supported by two massive concrete piers, a cannon mounted on a truck, a track upon which the truck rests, and an automatic recording device. The mortar weighs 31,600 pounds and hangs in two U-shaped rods. The rods pass through and are held by two cast-steel saddles which fit over the supported beam. The radius of the swing measured from the point of the knife edges to the center of the trunnions is $89\frac{3}{4}$ inches.

The cannon is 24 inches in diameter and 36 inches long, and its axial bore is $2\frac{1}{4}$ inches in diameter and $21\frac{1}{2}$ inches deep.

The swing of the mortar is measured by an automatic recording device which consists of a movable scale and a vernier set on a metal base fastened to a concrete footing. The scale is actuated by a long rod set in guides which bears against a stud bolt in the bottom of the mortar directly below its center of gravity. The scale moves tangentially to the swing of the mortar; the radius of the swing, measured from the knife-edge bearings to the center of the rod or base of the stud, is $114\frac{7}{16}$ inches. The swing is measured to one hundredths of an inch. The standard unit of comparison is a charge of 227 grams (one-half pound) of 40 per cent "straight" nitroglycerin dynamite.

The explosive to be tested is charged in the cannon without air space around the charge. One pound of dry fire clay is used as stemming to confine the charge. The charge is fired with a No. 6 electric detonator and each result reported herein is the average of two trials agreeing within 5 per cent. In testing, the method of procedure is as follows:

Two trials are made with 227 grams of the Pittsburgh station standard 40 per cent "straight" nitroglycerin dynamite, and the average of the two swings is taken as the unit swing. One preliminary trial, or more if necessary, is then made with the explosives being tested to determine the approximate unit deflective charge. Two trials are then made with this weight of explosive and if the average swing of these two trials is within two-tenths of an inch of the standard swing the unit deflective charge is computed from this preliminary charge by direct proportion, as follows: The average swing for the explosive is to the unit swing as the trial charge is to the unit deflective charge. The distance of the cannon from the muzzle of the mortar is always one-sixteenth of an inch, a slight separation being necessary for the passage of the legs of the electric detonator or electric igniter. In order that the mortar may always hang from the same center the knife edges are trammed before each trial.

The results of tests made to determine the propulsive effect of the various classes of explosives as measured by the pressure gages ^a and the ballistic pendulum are given in the accompanying tabulation.

^a See Bichel, C. E., *New methods of testing explosives*, 1905, pp. 54-62.

Results of tests of the propulsive effect of explosives.

Class and grade of explosive.	Diameter of cartridge.	Number of electric detonator.	Specific gravity of cartridge.	Pressure gage.			Ballistic pendulum.		Heat evolved by 100 grams of explosive.	Calorimeter percentage.	Weight of charge.	Volume of permanent gases from 454 grams of explosive.
				Kilograms per square centimeter.	Pounds per square inch.	Percentage strength.	Charge equivalent to 227 grams of 40 per cent standard nitroglycerin dynamite.	Percentage strength.				
30 per cent "straight" nitroglycerin dynamite.	<i>In.</i> 1½	6	1.31	8,874	126,230	<i>a</i> 104.3	<i>Grams.</i> 254	89.4	<i>Calor.</i> 1,025.8	93.1	<i>Gr.</i> 214.0	<i>Liters.</i> 182
40 per cent "straight" nitroglycerin dynamite.	1½	6	1.24	8,509	121,030	<i>a</i> 100.0	227	100.0	1,101.8	100.0	213.0	189
50 per cent "straight" nitroglycerin dynamite.	1½	6	1.38	9,301	132,300	109.3	215	105.6	1,222.6	111.0	213.0	225
60 per cent "straight" nitroglycerin dynamite.	1½	6	1.37	10,311	146,670	121.2	209	108.6	1,145.8	<i>b</i> 104.0	213.5	274
60 per cent strength low-freezing dynamite	1½	6	1.14	6,797	95,830	79.2	220	103.2	663.4	<i>c</i> 0.2	213.4	361
40 per cent strength ammonia dynamite..	1½	6	1.57	8,921	126,890	104.8	243	93.4	1,122.0	<i>d</i> 101.8	212.0	140
40 per cent strength gelatin dynamite.....	1½	6	1.65	8,444	120,110	99.2	246	92.3	1,164.6	105.7	207.0	132
5 per cent granulated nitroglycerin powder.	1½	<i>e</i> 6	1.21	3,350	47,650	39.4	338	67.2	744.4	67.6	205.0	136
Black blasting powder.	1½	(<i>f</i>)	1.25	4,817	68,520	56.6	374	60.7	789.4	71.6	205.0	150

^a Seeming discrepancy due to difference in specific gravity.
^b The low calorific value is due to the rather large volume of hydrogen and carbon monoxide formed, and to the fact that the calorimeter leaked slightly because of high pressures.
^c The low calorific value is due to the large volume of hydrogen and carbon monoxide formed.
^d No correction made for heat of condensation of water.
^e A primer of 40 per cent "straight" nitroglycerin dynamite, representing 10 per cent by weight of the charge, was used in all tests, but the energy produced by the primer is not included.
^f Black-powder igniter used.

COMPARISON OF EXPLOSIVES AS TO ENERGY.

As a result of tests the tabulation following has been prepared to show a comparison of various classes and grades of explosives as to potential energy and disruptive and propulsive effects.

The percentage strength representing potential energy is the result obtained with tests with the calorimeter; the percentage strength representing disruptive effect is the average of the rate of detonation, Trauzl lead block, and small lead block percentages; and the percentage strength representing propulsive effect is the average of the pressure-gage and the ballistic-pendulum percentages. In each case the 40 per cent "straight" nitroglycerin dynamite is taken as the unit of comparison with a value of 100 per cent.

Results of tests to determine potential energy and disruptive and propulsive effects of explosives.

Class and grade.	Percentage strength representing potential energy.	Average percentage strength representing disruptive effect.	Average percentage strength representing propulsive effect.
30 per cent "straight" nitroglycerin dynamite.....	93.1	84.1	96.8
40 per cent "straight" nitroglycerin dynamite.....	100.0	100.0	100.0
50 per cent "straight" nitroglycerin dynamite.....	111.0	109.2	107.4
60 per cent "straight" nitroglycerin dynamite.....	104.0	119.8	114.9
60 per cent strength low-freezing dynamite.....	60.2	93.5	91.2
40 per cent strength ammonia dynamite.....	101.8	67.9	99.1
40 per cent strength gelatin dynamite.....	105.7	78.4	95.8
5 per cent granulated nitroglycerin powder.....	67.6	21.6	53.3
Black blasting powder.....	71.6	6.8	58.6

The relative disruptive and propulsive effects tabulated above are shown graphically in figure 7.

PRACTICAL VALUE OF PHYSICAL TESTS.

The figures given in the foregoing table are fairly consistent with general practice, and it is believed that the classification will serve as

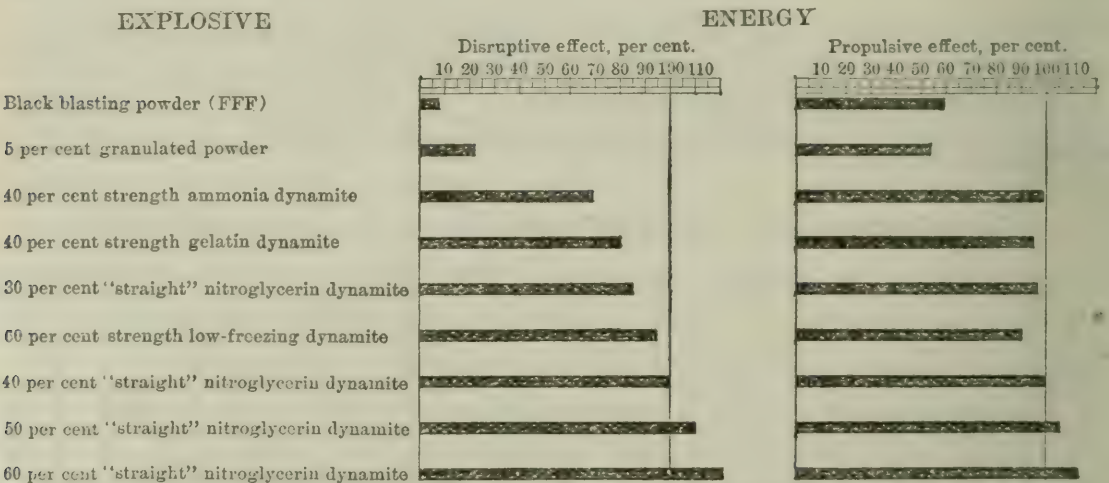


FIGURE 7.—Comparative energies of commercial explosives. Disruptive effect indicated represents averages of energies developed in the Trauzl lead-block, small lead block, and rate-of-detonation tests; propulsive effect indicated represents averages of ballistic-pendulum and pressure-gage tests.

a useful guide for comparing the practical value of explosives. It is worthy of note that the potential energy of 40 per cent strength ammonia dynamite and of 40 per cent strength gelatin dynamite (that is, the theoretical maximum work that these explosives can accomplish) is higher than that of 40 per cent "straight" nitroglycerin dynamite, but that the disruptive and propulsive effects, which represent the useful work done as shown by actual tests, are less than those of 40 per cent dynamite. Accordingly, 40 per cent "straight" nitroglycerin dynamite is more economical for general use in blasting operations if the conditions and character of the work are such as to permit its use; nevertheless, the 40 per cent strength

ammonia dynamite and the 40 per cent strength gelatin dynamite are more efficient and economical for certain kinds of work that require explosives having a large propulsive effect and a comparatively small disruptive effect. For example, in blasting soft rock, 40 per cent "straight" nitroglycerin dynamite, which has a very high percussive force, may be too quick in action, whereas the ammonia dynamite or the gelatin dynamite having practically the same heaving and pushing action and less percussive force will be more suitable. The tests also show that 60 per cent strength low-freezing dynamite is not quite equivalent to the 40 per cent "straight" nitroglycerin dynamite. The 60 per cent strength low-freezing dynamite contained, by analysis, 2.61 per cent moisture and 41.43 per cent nitroglycerin. This content may be cited as one of the many reasons for the need of uniform rating of explosives in this country. It is worthy of note that black blasting powder has little disruptive effect; it has only about one-third of the disruptive effect of granulated nitroglycerin powder.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls.

BULLETIN 15. Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 44. First national mine-safety demonstration, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine, by G. S. Rice. 1912. 75 pp., 7 pls.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 12 pp.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 12. The behavior of nitroglycerin when heated, by W. O. Snelling and C. G. Storm. 1912. 14 pp., 1 pl.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The prevention of mine explosions; report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 23. Ignition of mine gas by miniature electric lamps, by H. H. Clark. 1912. 5 pp.

TECHNICAL PAPER 24. Mine fires, a preliminary study, by G. S. Rice. 1912. 51 pp.

TECHNICAL PAPER 28. Ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 8 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines, their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1912. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.

MINERS' CIRCULAR 9. Accidents from falls of roof and coal, by G. S. Rice. 1912. 16 pp.

MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1913. 14 pp.



